

EXTRACTABLE MINERALS IN NINE MALAYSIAN SOILS AND THEIR EFFECT
ON THE MINERAL CONTENTS OF FOUR Hevea CLONES

By

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To my parents, brothers, and sisters,
in loving appreciation
for your tender solicitude for my happiness
and comfort, and

. . .

your quiet encouragement in my
hopes and aspirations.

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Three extractants, ethylenediaminetetraacetic acid + triethanolamine (EDTA-TEA), $0.025 \text{ N H}_2\text{SO}_4 + 0.05 \text{ N HCl}$ (DA), and 5 N HCl , were used to determine the extractable minerals in nine soil series used for rubber [Hevea brasiliensis (Willd. ex A. Juss) Müll Arg.] production in Peninsular Malaysia. Boron was determined by hot water extraction. Soil samples represented 0-15 and 15-30 cm depths in the tree-row and inter-row while profile samples represented four genetic horizons.

Relationship between mineral contents of soils and tissues of Hevea clone RRIM 600 growing on nine soil series was examined. Differences among clones as related to soil series were measured by collecting tissues from four different clones growing on two contrasting soil series. Tissues from these clones were collected in successive years to evaluate annual variations in mineral contents.

The reagent EDTA-TEA extracted the least amount of minerals from the soils except extractable P on Subang and Melaka, two soils very high in extractable Fe, exceeded that removed by DA. Extractable P, Cu, Zn, Mn, Fe, and Al were significantly higher by 5 N HCl procedure. The

DA reagent was generally equal to 5 N HCl in K and Mg extractions, and intermediate for other elements.

Fertility status of soils in this study was low, relative to most temperate soils. Mineral variations were attributed to clay minerals, quantity of clay and organic matter present, and cultural practices. Extractable micronutrients ranged from low to adequate, except Fe which was generally high. Micronutrient reserves were influenced by geochemical aspects of soil formation. Extractable Al ranged from 51 to 5350 ppm as extracted by EDTA-TEA and 5 N HCl, respectively.

Distribution of mineral contents within soil profiles indicated poor reserves for many mineral elements. Leaching losses and (or) plant uptake resulted in low levels of K, Ca, and Mg. Extractable micronutrients changed very little with soil depth except for alluvial soils with lower horizons high in organic matter where 5 N HCl extractable Zn (12 ppm) and Mn (11 ppm) greatly exceeded levels found in other horizons.

Hevea grown on a number of soils contained below optimum levels of P, Mg, Cu, Fe, and B in the leaves. Increased latex production was related to higher Mn concentrations in leaves and soils; however, there was no conclusive trend to infer that a specific nutrient (or nutrients) was involved directly in limiting latex yield. It is possible that interactions between nutrients and nutrient ratios exert considerable influence on latex production.

Significant differences in leaf mineral contents found among the four Hevea clones could not be clearly attributed to clonal or soil effects because of wide variations in extractable minerals within a soil

series. Variations in mineral contents of bark and bark-scrap rubber sampled in successive years were not good indicators of fertilizer responses.

Correlations of minerals in Hevea tissues and soil extractable minerals by the three extractants for soil samples taken from several sites were inconsistent or non-existent except for Mg and Mn where r values as high as 0.396 and 0.731, respectively, were found. Differences in soil series combined with types and methods of fertilizer application seem to prevent good overall correlations.

Relatively high concentrations of micronutrients, especially Cu (1 to 9 ppm), Zn (26 to 66 ppm), and Mn (78 to 287 ppm), were found in the bark-scrap rubber. Long-term effects of continuous crop removal, plus an increase in latex production stimulated by macronutrient fertilization, could result in an appreciable depletion of these elements since reserves of these elements appear to be quite limited.

INTRODUCTION

Peninsular Malaysia (Fig. 1) is situated at the southernmost part of the Thai/Malay Peninsula, extending from 1° 20' North to 6° 45' North with a greatest east-west width of about 320 km. It is bordered on the north by Thailand, on the south by Singapore, on the east by the South China Sea, and on the west by the Straits of Malacca. The total land area is about 130,000 km².

Climate

The climate of the peninsula generally belongs to Koppen's Tropical Rainforest Climate (Af) which is defined as having no distinct dry season and a monthly average temperature above 18 C in the coldest month. The peninsula is in the area of lower latitudes and experiences very small fluctuations in temperature throughout the year in its lowland areas where the mean annual temperature ranges from 25.6 C to 27.5 C. The range of fluctuation for the mean monthly temperature is only 1.4 C for the minimum and a little more than 3 C for the maximum in the north-eastern region. Diurnal changes in temperature are also small, about 5 to 8 C for coastal areas and about 8 to 11 C for inland areas.

Rainfall pattern is the most marked feature in the northwest and the east coast regions. In the northwest coastal plain, rainfall during the northeast monsoon season is quite low in January and February while

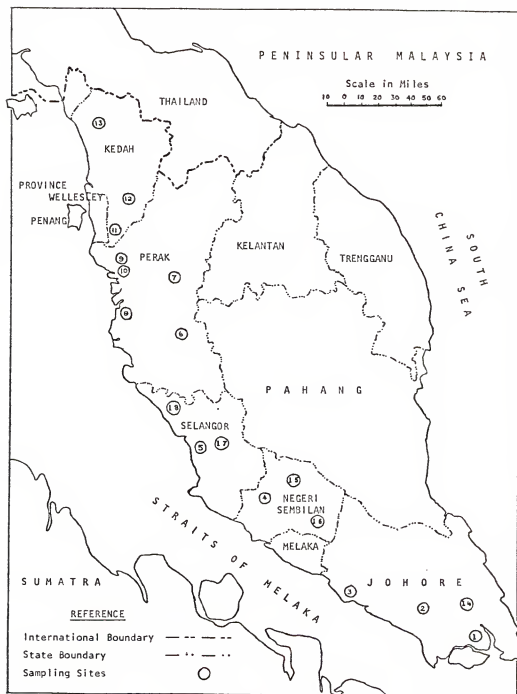


Fig. 1. Locations from which *Hevea* tissues and soil samples were obtained.

the highest rainfall occurs in the September-October period. On the east coast, more than 50% of the precipitation occurs in the January-February northeast monsoon season and the remainder of the year is relatively dry. Fluctuation of monthly rainfall generally decreases southward, where rainfall tends to be distributed evenly throughout the year. The annual rainfall ranges from 1,700 to 4,200 mm inland of the west Main Range, from 1,900 to 2,400 mm on the west coast, and from 2,800 to 3,100 mm on the east coast.

Topography and Geology

About 40% of the total land area is hilly or mountainous rising above 150 m and more than half of this (23% of the total) extends above the 300 m contour. There are several mountain ranges aligned, generally, in a north-south direction of which the largest (commonly known as the Main Range) is usually considered the backbone of the country, as it more or less divides the peninsula into west and east coast.

The land between about 15 to 150 m above sea level can be described as gently to moderately undulating, while large flat areas of peat swamps and alluvia are found along the west coast rising from sea level to about 15 m and extending inland at places to a maximum of 60 km. Along the east coast these flat alluvial areas are not well represented.

The mountain ranges and the lower areas of undulating land are mostly composed of granitic rocks as well as old bedded rocks of the Mesozoic and Paleozoic eras. Granitic rocks have the most widespread distribution, underlying almost half of the total surface area. The older sedimentary rocks consist of repeated series of quartzites and

shales with interbedded limestones and volcanic rocks. Rocks younger than the granites occur only in small patches and are of minor importance as soil parent materials.

Flat land areas along the coast and a part of the undulating hill lands (not exceeding 80 m above sea level) represent the major part of the Quaternary sediments. The older alluvium is comprised of unconsolidated clays, sands, and gravel. Similar formations are known to occur in other parts of the peninsula at higher levels (up to 80 m above sea level) further inland taking the form of raised terraces or coastal platforms. Lower-level terraces with flat to gently undulating landforms, intermediate in elevation as well as in age, are known to occur in some parts of the peninsula between the older alluvium and recent alluvium. These are composed of predominantly coarse textured "subrecent" alluvium.

Recent alluvia occupy the flat low-lying land along the coast and in intermontane valleys. Flow rates of Malaysian rivers decrease very rapidly at the foot of mountains where elevations are less than 30 m above sea level. As a result there is a reduction in the carrying capacity of the rivers and much of the coarse and medium grained materials is deposited at the landward margins of the coastal alluvial plain in a fresh water condition. Finer grained materials carried by sluggishly meandering rivers are deposited later in a brackish water milieu or in a marine condition at the mouths of rivers and along the coastal stretches. This zoning of marine and river sediments, roughly parallel to the coast line, is typically seen on the west coast. In some of the larger stretches of alluvia along the west coast permanent swamp conditions in the centers have built up thick peat layers.

Although the climate of Malaysia as characterized by its high temperature and high rainfall exerts a tremendous influence on the weathering and soil forming processes, the parent material is also important in soil genesis in Malaysia.

Major Crop--Rubber [*Hevea brasiliensis*
(Willd. ex A. Juss) Müll. Arg.]

Hevea is a native of the Amazon Basin and was first introduced to Malaysia in 1867. It proved to be easily adapted to the local environment and production has steadily increased so that in 1978 an estimated two million hectares of the crop are being grown in the peninsula. As a major agricultural crop in the country, Hevea has played a very important role to the Malaysian economy. Malaysia leads in world natural rubber production, exporting nearly two million metric tons annually which accounts for about 45% of the world's total output. Hevea trees are being extensively cultivated on the subrecent and older alluvial terraces soils of the peninsula. Major Hevea growing areas are found along the west coast of the peninsula, stretching from the northern to the southern States of Kedah, Perak, Selangor, Negeri Sembilan, and Johore. In the present study, nine of the soil series commonly used for Hevea production were obtained from those States.

Hevea is a perennial crop with an average economic life span of about 25 years. Continuous maximum production of Hevea depends largely upon optimum agro-management during its life-cycle. The use of mineral fertilizers accounts for 30 to 40% of the cost of agronomic inputs in Hevea production under optimum management. Most Hevea fertility programs

and nutritional investigations have been focussed on macronutrient needs. Little is known about micronutrient requirements for growth and development of Hevea in the field, although during the mid-1950's Bolle-Jones (1956 and 1957c) demonstrated the importance of micronutrients for the growth of Hevea seedlings. Subsequent work to assess or survey the total content and availability of micronutrients in Malaysian soils, particularly under Hevea cultivation, is rather limited.

The trend towards use of potentially high yielding clones, intercropping with soybeans (Glycine max L.), and other food crops in immature Hevea plantings and increasing rates of macronutrient fertilization results in greater crop removal of micronutrients. As the use of high analysis macronutrient fertilizers increases, demand on the native soil micronutrient supply will also increase. There will be a greater need to understand the role of micronutrients as an integral part of a total soil fertility program. This will require knowledge of the total micronutrient reserves in the soil as well as factors affecting their availability to plants. Plant requirements for micronutrients are determined by plant uptake and utilization and through growth and yield responses. If there is a need for one or more of the micronutrients, it will be necessary to select efficient and economical sources and to develop methods of application.

This research was conducted with the following objectives:

- 1) to evaluate the fertility status, with particular emphasis on micronutrients, of some Malaysian soils commonly used for Hevea production;
- 2) to determine the relationships between the mineral nutrient contents in soil, leaf, bark, and bark-scrap rubber of Hevea;

- 3) to compare the variations of mineral levels in tissues of four Hevea clones (RRIM 600, RRIM 605, PB 5/51, and GT 1) when planted on two contrasting soil series (Munchong and Holyrood);
- 4) to compare the variations in mineral levels in tissues of Hevea from one year to another;
- 5) to determine the distribution of plant mineral nutrients within soil profiles; and
- 6) to make practical recommendations for sampling procedures and the extracting reagents that may be adapted for routine nutrient analysis of Malaysian soils based on correlation of minerals in soil extracts with mineral levels in leaf, bark, and bark-scrap rubber.

LITERATURE REVIEW

Micronutrient Elements in Soils

Since excellent extensive reviews on the geochemistry and mineralogy of micronutrients are available (Hodgson, 1963; Krauskopf, 1972; Norrish, 1975), the following discussion will briefly summarize the present knowledge on the occurrence and forms of micronutrients in soils and some important factors affecting their availability to the plants.

Forms and Occurrence in Soils

Micronutrient elements may be present in soils in relatively large quantities but in various forms. Hodgson (1963) suggested that they may be (1) precipitated with other soil components to form a new solid phase; (2) occluded during formation of new solid phases in which the nutrient is not a principal constituent; (3) included in soil minerals during crystallization of state diffusion; (4) associated with soil surfaces, either organic or inorganic; and (5) incorporated in biological systems. Loneragan (1975) stated that the rate of micronutrients released into the soil solution, from included forms, are extremely slow, whereas release from soil surfaces would be rapid.

The concentrations and forms of micronutrient elements in soil solutions have been investigated. Lindsay (1972) reported that in acid soils, Cu, Zn, and Mn ions are in divalent forms, M^{2+} . He also stated

that in neutral and alkaline soils the monovalent hydroxy cation, $M(OH)^+$, would be important. However, several investigators (Hodgson et al., 1966; and Geering et al., 1969) reported that appreciable quantities of micronutrients extracted from the surface soils occurred as complexes. In general, they found that about 50% of Zn, and up to 90% of Mn were complexed by organic compounds in the soil solution. Hodgson et al. (1966) showed that more than 98% of Cu in soil solution was in an organic complex form. Thus in neutral soils very small quantities of free Cu^{2+} are available for adsorption reactions.

Bingham et al. (1964) reported that montmorillonite is capable of adsorbing Zn or Cu beyond its cation exchange capacity, particularly at near-neutral or alkaline pH levels. They attributed this to adsorption of the hydrolyzed form or precipitation of the hydroxides, $Zn(OH)_2$ or $Cu(OH)_2$. DeMumbrum and Jackson (1956) observed that Ca-montmorillonite and Ca-peat could accumulate Zn or Cu from very dilute, neutral solutions either in the presence or absence of excess Ca ions. They suggested that montmorillonite and peat had specific exchange sites for Zn and/or Cu. Nelson and Melsted (1955) showed that a certain portion of Zn adsorbed on clay was not exchangeable, but was acid soluble. Reddy and Perkins (1974) found that kaolinitic clay fixed less Zn than either bentonite or illite and that fixed Zn was not substituted for lattice ions, but was strongly adsorbed. They found an inverse relation between CEC and Zn fixation. Earlier, Thomas and Swoboda (1963) showed that pH and CEC were the controlling factors in the amounts of Zn adsorbed by kaolinite, hydrous iron oxides, and clay-iron oxide complexes.

Ellis and Knezek (1972) stated that in well-aerated soils, Fe and Mn oxides, hydroxides, and phosphates would be of major importance in

controlling the level of these micronutrients in solution and their availability to plants. Under reducing conditions both Fe^{2+} and Mn^{2+} are known to increase in solubility to the point where they become adsorbed as exchangeable ions (Mandall, 1961).

Christiansen et al. (1950) found that concentrations of exchangeable Mn decreased by a factor of 20 to 50 when the soil acidity was decreased from pH 4.6 to 6.5. It was also shown that as soil moisture increased, exchangeable Mn decreased. However, pH and moisture changes had little or no effect on the exchangeable or easily reducible Fe.

Precipitation of Mn as MnO_2 appears to be an important reaction governing the concentration of Mn^{2+} in soil solutions (Leeper, 1947). The relationship of Mn^{2+} to MnO_2 is affected by factors influencing the kinetics of the reaction, which appear to depend more on current microbiological activity than on physico-chemical factors alone. This may partly explain the very large and rapid fluctuations which occur in the Mn concentrations of soil solutions, as well as their sensitivity to soil pH, aeration, and sterilization (Mulder and Gerretsen, 1952; Geering et al., 1969).

Several authors (Stevenson and Ardakani, 1971; Schnitzer and Khan, 1972) have published excellent reviews on the reactions of micronutrients with soil organic matter. The reactions included ion exchange, chelation, and complex formation. These authors attributed the formation of complexes and chelates to the interactions between metal ions and organic matter through COOH , phenolic OH , C=O , and NH_2 functional groups. The order of bonding of divalent metal ions varies with organic matter in different soils. Of the divalent metal ions, Cu^{2+} is generally the most strongly bonded. The bonding of Zn^{2+} and Mn^{2+} is usually appreciably

weaker. Both Fe^{3+} and Al^{3+} are more strongly bound than Cu^{2+} at acid pH values. Schnitzer and Skinner (1963) found that with increasing pH, the stabilities of the metal-organic complexes decreased with the formation of hydroxides.

Hodgson (1963) pointed out that B was adsorbed on clay surfaces in a manner similar to that of heavy metals rather than as an anion. Several investigators proposed that the major inorganic sites for B adsorption are (1) Fe- and Al-hydroxy compounds present as coatings on or associated with clay minerals (Hatcher et al., 1967; Sims and Bingham, 1968a); (2) Fe or Al oxides (Scharrer et al., 1956); (3) clay minerals, particularly of micaceous-type (Sims and Bingham, 1967; Couch and Grim, 1968); and (4) Mg-hydroxy clusters or coatings that exist on the weathered surfaces of ferromagnesian minerals (Rhoades et al., 1970).

Berger and Truog (1945) found that available B was positively correlated with the organic matter content of soils. Parks and White (1952) reported that a large amount of B was fixed by humus, and suggested that the mechanism of fixation may be through B uniting with diols of the organic matter or carbohydrates released as intermediates of organic matter decomposition.

Molybdate is sorbed strongly by iron oxides and hydrous oxides (Reisenauer et al., 1962; Reyes and Jurinak, 1967), but Al oxides also complex Mo (Jones, 1957). A portion of the sorbed Mo becomes unavailable to the plant, while the remainder is in equilibrium with the soil solution. As plant roots remove Mo from solution more Mo is desorbed into the solution by simple mass action (Jarrel and Dawson, 1978). Perrot et al. (1976) proposed an indirect measure of the ability of soil to sorb Mo by determining the amount of amorphous Fe and Al in the soil.

Factors Affecting Availability of Micronutrients

Hodgson (1963) stated that the degree of availability of micronutrients in soils is a function of their partition among different forms--a partition that is influenced by many factors. The forms have been discussed earlier, and each form is related directly or indirectly to the soil solution through some equilibrium distribution that is a function of the pH, oxidation potential, and supply and activity of individual soil constituents. In natural environments a delicate balance exists between the micronutrient ions that occur in the soil solution (free ions, soluble chelates, and insoluble mineral and organic forms) (Stevenson and Ardakani, 1972).

Soil pH

The availability of micronutrients is highly related to soil pH. In general, decreasing pH strongly depresses the rates of absorption of B and Mo but promotes the adsorption of the metallic cations when they are present as inorganic ions (Loneragan, 1975). The availability of Cu is dependent upon soil pH but does not normally increase appreciably until the pH falls below 5.0. Lucas (1946), working with a very acid organic soil limed at various rates, obtained the least response in Sudangrass at pH 5.5 while marked response was obtained at pH levels above 7.0 and below 4.5. Norvell and Lindsay (1969) reported that below pH 7.3 Cu^{2+} predominates in soil solution, while above this pH, CuOH^+ is most abundant. Hodgson et al. (1966) believed that strong complexing of Cu by soil organic matter is an important factor explaining why Cu deficiencies are not as prevalent as Zn deficiencies on high pH soil

even though both cations show similar decrease in solubility with increase in pH.

The Mn^{2+} ion is the predominant species in soil solution and decreases 100-fold for each unit increase in pH (Lindsay, 1972). The solubility of Mn in soils is highly variable and pH dependent (Bohn, 1970). Geering et al. (1969) reported values near 0.01 ppm for total Mn and calculated 0.0003 ppm for Mn^{2+} . The higher solubility of Mn in soils may be due to formation of coprecipitates of Mn oxides with other heavy metals, particularly Fe.

Most of the Zn disorders in plants occur in calcareous soils, probably the result of low solubility products of Zn soil complexes and carbonates (Udo et al., 1970). Lindsay (1972) stated that at pH below 7.7, the predominant species is Zn^{2+} and its solubility is highly pH-dependent and decreases 100-fold for each unit increase in pH. At low pH values, some Zn^{2+} may be present on the exchange complex of soils, but at high pH values, the levels of Zn^{2+} in solution is so low that very little Zn^{2+} will be held on the exchange complex.

The solubility of Fe in soils is largely controlled by Fe oxides. The Fe^{2+} and Fe^{3+} activity in solution decreases 100 and 1000-fold, respectively, for each unit increase in pH (Lindsay, 1972). In acid soils, amorphous and crystalline Fe phosphates are known to form (Lindsay et al., 1962). However, total P in soils is generally much less than total Fe, so even if all P were precipitated as Fe phosphates, hydrous Fe oxides could still maintain the soluble Fe levels in soil solution. The adsorption of B on oxides of Fe and Al is believed to be an important mechanism governing B solubility in soils and clays (Sims and Bingham, 1968b)

Fox (1968) reported that high levels of Ca and high pH values reduced B uptake by nearly 50% in cotton. He proposed that B adsorption mechanism was affected either by the presence of high concentrations of Ca^{2+} and OH^- , or by the secretion of H^+ or CO_2 by the roots. In contrast to the other micronutrients, Mo deficiency is usually associated with soils below pH 5.5. The reduced Mo solubility at low pH levels may be enhanced by reactions with Fe and Al. The beneficial effects of liming acid soils to increase Mo solubility are obvious, the MoO_4^{2-} concentration increases 100-fold for each unit increase in pH (Lindsay, 1972).

Organic Matter

Hodgson (1963) proposed three principal categories of organic matter-micronutrient complexes in soils. These include (1) the relatively high molecular weight humic substances containing condensed aromatic nuclei, which have a high affinity for micronutrients but are largely insoluble in soil; (2) low molecular weight organic acids and bases derived largely from microbial cells and metabolism which demonstrate relatively high solubility in association with micronutrients; and (3) soluble ligands which are precipitated on reaction with micronutrients.

Humic and fulvic acids in the soil organic matter account for most of the micronutrient immobilization. They have the potential for the formation of soluble micronutrient complexes, particularly in dilute solutions (Hodgson, 1963; Stevenson and Ardakani, 1972). The production, distribution, and action of organic acids in soil has been reviewed by Stevenson (1967). Stevenson and Ardakani (1972) concluded that

water-soluble organic acids and amino acids, while present only in small quantities in soil, played a significant role in solubilization of micronutrients.

Microbiological and Root Exudates

By far the most widely studied and probably the most important microbiological effects on the availability of micronutrients involved the oxidation and reduction of Fe and Mn. Reduction of Fe^{3+} to the more soluble Fe^{2+} compounds coupled with the oxidation of organic matter is brought about by common heterotrophic bacteria of the genera Bacillus, Pseudomonas, and Clostridium in soil (Alexander, 1961). Degradation of inorganic and organic Fe compounds, including chelates and complexes, is a widespread biological occurrence which tends to release and precipitate Fe^{3+} (Martin and Focht, 1977). Other microbiological processes result in a reverse procedure by reducing pH as well as compounds capable of complexing or chelating Fe^{3+} and thereby increasing the solubility of Fe.

Studies have shown that soil organisms can induce Mn deficiencies by oxidizing Mn^{2+} to Mn^{4+} (Mulder and Gerretsen, 1952) when the soil reaction is near neutrality or alkaline (Meek et al., 1968). Microbial metabolism also increases the level of Mn^{2+} by reduction, removal of O_2 , or the formation of acid products.

Root exudates contribute directly to increasing the rate of release of insoluble nutrients in the soil (Bromfield, 1958), and may considerably change the pH in the soil surrounding the roots (Riley and Barber, 1969). The range of organic compounds released by plant roots

is extensive as indicated by the reviews of Rovira (1969). Bromfield (1958) showed that plant roots release substances that readily dissolve MnO_2 and that the acidic solution greatly increased the availability of indigenous Mn.

Oxidation and Reduction

Swaine and Mitchell (1960) noted that micronutrients are more easily removed from poorly-drained soils than from well-drained soil. This is particularly true for Cu, Mn, Mo, and Zn, which have increased mobility under reduced conditions. Recently, Sims and Patrick (1978) reported that the distribution of micronutrients within soil fractions was influenced by both pH and Eh (oxidation potential) although Fe and Mn were affected to a greater extent than Zn and Cu. They found that Fe mobilized by reductions was much higher than that of other micronutrients at low redox potentials. Ponnamperna (1972) found that Mn oxides and hydroxides were reduced more easily at higher redox potentials than Fe oxides and hydroxides after flooding. As a consequence, at the higher redox potentials relatively greater amounts of Mn than Fe were solubilized, permitting Mn to occupy the exchange sites first. From lysimeter studies, Lal and Taylor (1970) reported that, in general, soil drainage increased the uptake of Zn, Cu, and B, but decreased the uptake of Fe, Mn, and Mo by plants.

Principles of Micronutrient Soil Test

One of the problems associated with testing soils for micronutrient cations is the difference in crop sensitivity to the available supply of

these elements. Recognizing the problem, Bray (1948) proposed that a good soil test should meet the following three criteria: (1) The extractant used should extract all or a proportionate part of the available form or forms of a nutrient from soils with variable properties; (2) the amount of nutrient extracted can be measured with reasonable accuracy and speed; and (3) the amount extracted can be correlated with the growth and response of each crop to that nutrient under various conditions.

Soil tests for micronutrients should extract a portion or all of three pools of micronutrients: (1) H_2O soluble; (2) exchangeable; and (3) adsorbed, chelated, or complexed (Viets, 1962). All of these forms are considered to be in equilibrium and available to the plant (Cox and Kamprath, 1972).

Methods of Micronutrient Soil Tests

Several new micronutrient soil tests have been developed in recent years. In an attempt to extract a measurable amount of an element to correlate with the plant's uptake, soil chemists have resorted to stronger extractants than the soil solution or water. For various reasons they have not always been correlated with crop response on other soil types. Basically three types of extractants have been used in estimating available micronutrients.

Water and Neutral Salts

A number of workers have used water to extract Cu (Kruglova, 1962), Mn (Shuman and Anderson, 1974), B (Berger and Truog, 1940), and Mo

(Gammon et al., 1954). Among these elements, B extraction by hot water has been widely accepted as the best index of availability for plants (Wear, 1965). A number of reports have indicated that hot water-soluble B correlates well with its uptake by the plants (Gupta and Munro, 1969; Baker and Mortensen, 1966). Martens (1968) used multiple regression analysis to show that B uptake by corn was best predicted by hot water-soluble B and soil pH.

Anderson and Boswell (1968) showed that cotton response was negatively correlated to water-soluble soil Mn. However, studies with other crops such as wheat (Shuman and Anderson, 1974) and oats (van Eysinga et al., 1978a) indicated that water-soluble soil Mn was a satisfactory measure of plant uptake. Barshad (1951) found that Mo content of two plant species was roughly proportional to the water-soluble soil Mo when the pH ranged between 4.7 and 7.5.

Generally, the concentration of water-soluble micronutrients in soils is very low. Gupta and McKay (1965, 1966) found that the amount of water-soluble Cu ranged from 0.09 to 0.46 ppm and that water-soluble Mo was not detected in half of the soils they analyzed. Manganese content in acid soils as extracted by water ranged from 0 to 6.3 ppm and increased as soil pH decreased (Morris, 1948). Randall et al. (1976) reported that in 37 Wisconsin soils with low organic matter (less than 6%), Mn content extracted by water ranged from 0.1 to 2.0 ppm. He also found that Mn extracted by water in 20 Wisconsin soils with a high organic matter content (greater than 20%) could not be detected by an atomic absorption unit.

In ten selected Louisiana soils, Sedberry and Reddy (1976) reported that water-soluble Zn varied from 0.05 to 1.33 ppm and that coarse

textured soils contained more water-soluble than exchangeable Zn. Since the amount of water-soluble micronutrient cations in the soil solution is very small, analytical problems are encountered, and often the results are quite variable.

Soil tests for micronutrients by neutral salts have been successfully used by many investigators. Hoyt and Nyborg (1971) found that 0.01 M CaCl_2 was superior to other salts and weak acids as an extractant for high levels of Mn in acid soils as shown by highest correlation coefficients with Mn concentration in barley, turnip, rape, and alfalfa grown in a greenhouse. Most recently, van Eysinga et al. (1978b) studied 102 Netherlands' soils and reported that soil Zn extracted with $\text{N NH}_4\text{OAc}$ at pH 7.0 gave a better correlation with Zn content of oats, than Na-EDTA (ethylenediaminetetraacetic acid) in water. Martens (1968) studied extractions with 2 N MgCl_2 and 0.1 and 1.0 N HCl to predict Zn uptake by greenhouse corn. He found that the 2 N MgCl_2 -extractable Zn was most closely related to Zn uptake. Mortvedt (1977) cautioned that high salt concentrations in extracts usually caused plugging of the atomic absorption burners, thus discouraging use of such extractants for routine soil test analyses.

Weak and Strong Acid

More micronutrient extraction and calibration work has probably been done with HCl than with any other acid. Wear and Sommer (1948) first reported the feasibility of using 0.1 N HCl procedure for determination of available Zn, which later became widely used. Primary sources of information on 0.1 N HCl vs. other extractants include Martens et al.

(1974), Nelson et al. (1959), and van Eysinga et al. (1978b) for Zn; Dolar et al. (1971), Vitosh et al. (1973), and Randall et al. (1976) for Cu, Zn, and Mn. Sorensen et al. (1971) reported the effects of soil/solution ratio and length of extraction period of 0.1 N HCl on the extractibility of Zn, Fe, and Mn from 18 soils.

Nelson et al. (1959) found that the 0.1 N HCl extractant could be used for estimating available Zn on calcareous soils if proper adjustment was made for titratable alkalinity (a measure of free CaCO_3) in the soil. Later, Trierweiler and Lindsay (1969) reported that 0.1 N HCl extraction procedure was inadequate for separating Zn deficient from nondeficient of 42 Colorado soils; however, an $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ extractant provided a satisfactory separation. Failure of 0.1 N HCl to provide a good separation was attributed to the variable free CaCO_3 contents of these soils. Neutralization of the acid in these calcareous soils reduces acid strength and can result in lower levels of extractable Zn.

Many other combinations of salts and acids of various strengths have been compared with other methods and with plant uptake. Wear and Evans (1968) reported that a dilute acid mixture of 0.05 N HCl + 0.025 N H_2SO_4 (DA), routinely used by many soil testing laboratories in the southern region of the USA, was highly correlated with Zn uptake of corn grown in the greenhouse. They found a slightly lower correlation coefficient with 0.1 N HCl and much lower coefficient with 0.05 M EDTA at pH 7.0. Cox (1968) used DA-extractable Mn to calibrate the response of soybean to Mn fertilization and found that the test was useful over a pH range of 5.2 to 7.0. More recently, Mehlich (1978) proposed a new extractant which would allow a simultaneous extraction of several plant

nutrients including Zn and Mn over a wide range of soil properties. The new extractant is composed of 0.2 N NH_4Cl -0.2 N HOAc -0.015 N NH_4F -0.012 N HCl at pH 2.5, which Mehlich (1978) claims to be more suitable than the DA extractant for moderately acid and alkaline soils.

Chelating Agents

Recent studies indicate that chelating agents offer a great promise for assessing readily available micronutrient cations in soils. Lindsay and Norvell (1978) developed a DTPA (diethylenetriaminepentaacetic acid) extractant at pH 7.3 which has the most favorable combination of stability constants for the simultaneous complexing of Fe, Zn, Cu, and Mn. The soil test successfully separated 77 Colorado soils on the basis of crop response to Zn, Fe, and Mn fertilizers.

Haq and Miller (1972) used four extractants on 85 soils to predict available Zn, Cu, and Mn. For Zn, the correlation coefficients relating plant Zn to EDTA and DTPA-extractable soil Zn were 0.607 and 0.602, respectively. When pH was included in the regression equation, the correlation increased to 0.745 and 0.759, respectively. Their findings suggest that when DTPA is used to measure available Zn in soils below pH 7.0, inclusion of pH in the regression equation may improve its usefulness. This improvement may arise because Zn solubility in soils is strongly pH-dependent (Lindsay and Norvell, 1969). Equal quantities of labile Zn should show greater availability in acid than in alkaline soils.

Extraction of micronutrient cations from soils depends upon the binding strength of the chelating agent for the various metal ions as

well as the binding strength of the soil for these ions (Norvell, 1972). Norvell (1972) also reported that a number of chelating agents can effectively complex Cu and Zn in soils, but DTPA was especially useful in that it was also among the best chelating agents for Fe and Mn. Unlike most other chelating agents, DTPA is able to apply a moderate stress to solubilize soil Fe at a pH where CaCO_3 is not dissolved (Norvell and Lindsay, 1972). In a later study, Lindsay and Norvell (1978) reported that chelation of Mn by DTPA in extracting solution is more difficult to predict because it is redox dependent.

Atley et al. (1972) tested four extractants on 10 slightly acid to neutral soils from Virginia. They found that EDTA-ammonium carbonate (Trierweiler and Lindsay, 1969) or DTPA was superior to methods using dilute acid extractions. Recent studies by Soltanpour et al. (1976) demonstrated the importance of standardizing sample preparation and extraction procedures. These procedures are particularly important for Fe where the critical level of 4.5 ppm of DTPA-extractable Fe represents only about 0.01% of the total Fe in the soils. These workers further showed that critical soil test levels obtained under one set of standardized sample preparation and extraction procedures can be related through regression to those obtained using other standardized procedures.

The chelating agent EDTA has been used as an extractant for Cu, Zn, and Mn. Viro (1955) extracted soils with 0.05 M EDTA, and Jensen and Lamm (1961) used 0.02 M EDTA. Tucker and Kurtz (1955) extracted 14 acid and neutral soils from Illinois and showed a highly significant correlation between various extractants, including 0.007 M EDTA buffered at pH 7.0 with N NH_4OAc . In another study, Dolar et al. (1971) compared

the extractable micronutrients by various extractants as related to the nutrient uptake by oats and concluded that $\underline{\text{N}}$ NH_4OAc (pH 7.0), 0.01 $\underline{\text{M}}$ EDTA, and 0.1 $\underline{\text{N}}$ HCl were useful for assessing available Cu, Zn, and Mn in Wisconsin soils.

Calibration and Interpretation

Soil test results are mostly empirical and must be correlated with crop response on a large number of soils ranging from low to high levels of available micronutrients before they can be used for diagnostic purposes (Mortvedt, 1977). Increased crop growth resulting from micronutrient applications verifies that the soil is deficient for that micronutrient, at least under the conditions of that particular growth situation.

The concentration of chemically extractable micronutrients which separates deficient from nondeficient soils is called the critical soil level. Trierweiler and Lindsay (1969) used this approach to calibrate their EDTA- $(\text{NH}_4)_2\text{CO}_3$ soil test for available Zn on 42 Colorado soils. Soil test results greater than 1.4 ppm in available Zn were considered adequate for corn, while those with soil test levels below this critical value were classed as deficient. Brown et al. (1971) used the same approach to calibrate several extraction procedures for Zn on 92 California soils. Critical levels for soil Zn extracted by dithizone, DTPA, and EDTA were 0.55, 0.50, and 1.25 ppm, respectively. Mehlich and Bowling (1975) reported increased yields of wheat and soybeans with Cu applications to soils containing less than 0.5 ppm extractable Cu by 0.5 $\underline{\text{N}}$ HCl and 0.05 $\underline{\text{N}}$ AlCl_3 methods.

Another approach often used to calibrate soil tests is based upon plant uptake of micronutrients. Shuman et al. (1978) conducted field experiments with soybeans in which the treatments included Mn applications. Using a multiple regression test that includes soil pH, organic matter, and other variables for plant Mn-soil Mn correlation coefficients, they found that the DTPA and $0.1 \text{ N H}_3\text{PO}_4$ methods showed the highest correlation and the DA method the lowest. Evans et al. (1974) and Martens (1968) also related the amount of extractable Zn in soils to Zn uptake. This approach merely indicates how well a given extractant estimates the relative supplying power of a soil and does not give any indication of whether a soil is deficient or not (Cox and Kamprath, 1972).

Correlations of the concentration of extractable micronutrients in the soil with concentrations in plant tissue are often used in calibrating soil tests. Haq and Miller (1972) found that EDTA- and DTPA-extractable Zn in 85 Canadian soils reflected the concentration of Zn in corn grown on these soils under greenhouse conditions. These extractants were superior to EDDHA (ethylenediaminedi-o-hydroxyphenylacetic acid) and the DA. Hoff and Mederski (1956) used the same approach to show soil Mn extracted by $0.1 \text{ N H}_3\text{PO}_4$ or $3 \text{ N NH}_4\text{H}_2\text{PO}_4$ was highly correlated with Mn concentrations in soybeans. One assumption made in this approach is that nutrient concentrations in plants are directly related to the level of available nutrient in the soil (Mortvedt, 1977). Nutrient concentrations in plants are also related to growing conditions, amount of growth, and growth stage. If the rate of plant growth is reduced by low levels of nutrients other than the one under test, concentrations in the plant tissue can be higher than expected. Nutrient dilutions resulting from

increased growth rates also occur when the limiting factor has been removed (Terman et al., 1975). Thus, nutrient concentration and uptake, at least during early growth, should be evaluated in terms of growth rates and total dry matter production.

Inclusion of the effects of soil properties, such as pH, organic matter content, CEC, percent clay (a measure of soil texture), and available levels of other nutrients are necessary in the development of soil tests. From a greenhouse study, Randall et al. (1976) showed that plant availability of Mn is closely related to soil pH and that soil organic matter content should also be included in Mn soil test interpretation. Haq and Miller (1972) included the DA, EDDHA, EDTA, and DTPA extractants in a calibration study for determination of available Zn. They reported that if these extractants are to be used for acid soils varying in pH, the pH must be included in a regression equation to obtain a satisfactory interpretation of available Zn. Martens (1968) used multiple regression analyses to show that B uptake by corn was best correlated by hot water-soluble B and soil pH. He found Cu uptake was best predicted by inclusion of soil organic matter content with the level of N HCl-extractable Cu. The predictions of Zn uptake by 0.1 N or N HCl, or 2 N MgCl_2 extractable Zn were not improved by inclusion of soil pH, organic matter content, or percent clay.

During the development of a soil test, the investigators generally study the effects of changing the pH, soil/solution ratio, extraction time, or extractant concentration on the level of extractable micro-nutrient (Lam and Gammon, 1976). The extraction conditions which give soil test values that are best correlated with plant response are chosen.

However, extraction conditions must be adaptable for routine analysis if the soil test is to be practical.

Mineral Nutrient Requirements of Hevea

Investigations on fertilizer requirements of Hevea by the Rubber Research Institute of Malaya (RRIM) began in 1928. Since 1930's the importance of soils as a growth limiting factor for Hevea has been recognized (RRIM, 1930). Later, Owen (1951) established a provisional classification of Malayan soils based mainly on soil textural and parent material differences. Based on soil texture and results of fertilizer trials, N-P-K fertilizer mixtures were formulated for young rubber plants (RRIM, 1953). Since then a great deal of information has been accumulated which has made possible frequent revisions of fertilizer formulations in order to meet the optimum mineral requirements of the trees for a wide range of soils and conditions.

Macronutrient Needs

Nitrogen. Nitrogen is an essential nutrient for healthy growth and optimum latex production of Hevea trees. Nitrogen deficiency usually causes pale yellow foliage, sparse canopy and stunted growth. An adequate N fertilization in immature Hevea usually improves girdling. In mature Hevea, shortage of N will lead to a significant reduction of latex yield (Pushparajah and Guha, 1968). Bellis (1971) estimated that by following a fertilizer program as recommended by RRIM to cover 25 years of tapping, the N input over the entire planting life amounted to

between 950 and 1350 kg of N/ha. However, with the progress in development of high yielding clones and stimulation of higher yields, additional N input is necessary to compensate for the extra N drainage in the latex.

In the early years after planting considerable quantities of N are provided by the leguminous covers usually established between the rows of trees (Watson, 1957; Watson et al., 1964). However, in the non-legume cover areas, Pushparajah and Chellapah (1969) demonstrated the need of N application. Ammonium sulphate was reported to be more efficient than ammonium nitrate in promoting growth of young rubber (Soong, 1973). On coastal alluvial soils of Selangor series, field trials have shown that there is no difference in efficiency between urea and ammonium sulphate on growth of Hevea (Pushparajah, 1964).

Phosphorus. Phosphorus is one of the macronutrient elements required to increase Hevea growth and latex productivity (Owen et al. 1957). Collier and Lowe (1969) reported that P fertilization resulted in a general increase in the stability of latex concentrate. Shorrocks (1965) estimated that the average annual uptake of P per ha during maturity (excluding that withdrawn from latex) is about 32 kg P. He also reported that only 0.8 kg of P was removed in the latex sufficient to produce 1457 kg/ha/yr of dry rubber.

Phosphorus content of most Malaysian soils is low. However, the Kuantan and Selangor series contain sufficient P so that Hevea is unlikely to respond to P applications (RRIM, 1964). The beneficial effect of incorporating 114 g rock phosphate into the planting hole was observed in the early 1950's and later confirmed by a detailed investigation (RRIM, 1963). Mainstone (1969) reported that the amounts of P applied

to the tree and legume cover during immaturity would be adequate to meet the P requirements throughout most of the productive life of the tree. Pushparajah (1966) also observed that continued application of rock phosphate throughout the immature and mature phase of Hevea production can lead to latex yield depression even though positive growth responses were obtained. He attributed these yield reductions to the excessive Ca build-up in the tree, which was detrimental to latex flow. Shorrocks (1965) suggested that P application to mature trees would be necessary only when leaf analysis indicated a low P status that was confirmed by soil analysis.

Potassium. An adequate K nutrition is very important in Hevea in promoting growth increment, bark renewal, and increase in latex yield (Pushparajah, 1969). Potassium plays an active role in most of the physiological processes such as photosynthesis, protein and carbohydrate synthesis, and translocation of metabolites. Shorrocks (1965) estimated that the average annual uptake of K per ha during maturity for Hevea (excluding that withdrawn from the tree in latex) is about 142 kg. He also reported that the amount of K immobilized in the trunk and branches of 33 year old Hevea trees was about 786 kg/ha; however, the amount removed in the latex for the production of rubber was only about 2.6 kg/ha/yr of K.

The K content of Malaysian soils varies over a wide range; Haines and Crowther (1940) could detect no response by young Hevea to K on the Batu Anam soils, but Bolton (1960) found definite responses in soils derived from granite and others of low K status. In some instances depressive effects of K, particularly in the absence of N and Mg fertilizers, have been recorded (Bolton, 1964), but this may be caused by

K/Mg antagonism rather than any direct adverse effect of K. On Rengam soil, Pushparajah (1969) reported that the combination of N and K at 1.8 kg NH_4NO_3 and 0.23 kg KCl per tree increased yield more than 1000 kg/ha/yr.

According to Guha (1964), satisfactory leaf K can, in general, be expected when soil content is over 500 ppm. Bolton (1964) found that immature Hevea showed positive responses to K fertilization when the soil K content was 120 ppm and in some cases, 176 ppm. Shorrocks (1965) recommended annual maintenance application of 150 kg/ha KCl on soils of low K status and 50 kg/ha on high K status soils.

Magnesium. Magnesium is a constituent of chlorophyll molecule which is important in photosynthesis. In Hevea, Mg deficiency can result in a severe growth retardation which can affect both young seedlings and mature trees (Bolle-Jones, 1954a). The characteristic interveinal chlorosis, described and illustrated by Bolle-Jones (1956), has been reported on many different clones (particularly PB 86) and soil types. Shorrocks (1965) estimated that average annual uptake of Mg/ha during maturity (excluding that withdrawn from the tree in latex) is about 37 kg. He also estimated that 325 kg/ha of Mg was immobilized in the trunk and branches of 33 year old Hevea trees.

The applications of Mg limestones on Mg deficient trees have been reported to give positive responses in growth and latex yield (Bolton and Shorrocks, 1961). However, Mg limestone additions could also increase both the Mg content and Mg:P ratio of the latex. The Mg:P ratio has been related, under certain conditions, to stability of latex on the tapping cut and yield. Magnesium application on low K soils caused pre-coagulation on the tapping cut with consequent reduction of latex

yield; K additions have overcome this effect (Pushparajah, 1969).

Shorrocks (1965) found that kieserite was a better Mg source than Mg limestones (dolomite).

The Mg content of Malaysian soils varies over a wide range. Bolton (1964) demonstrated the limiting effect of low Mg status on growth responses to N, P, and K of young Hevea growth on fine textured soils derived from shale. Shorrocks (1965) suggested that on soils containing about 50 ppm Mg (acid-extractable), annual dressings of 150 kg/ha of kieserite should be applied while on better soils containing more than 100 ppm Mg, 50 kg/ha of kieserite should be satisfactory.

Micronutrient Needs

Very little information is available on the micronutrient requirements of Hevea. Most of the following discussions on these nutrients will be based on the limited work mostly done in the greenhouse with Hevea seedlings during the mid-1950's.

Copper. Copper is an activator of a group of oxidase enzymes and plays a vital function in the process of respiration. Hevea seedlings with Cu deficiency exhibited extensive apical defoliation, severe dieback, and marked stunting (Bolle-Jones, 1957a). Shorrocks (1965) estimated that the amount of Cu immobilized in a 33-year-old tree was about 4 kg/ha.

Under controlled conditions, Bolle-Jones (1957a) demonstrated that Cu deficiency in Hevea seedlings developed when the laminae contained between 2 to 3 ppm of Cu while healthy laminae possessed a Cu concentration of at least 10 ppm. He also found that increased Cu supply

increased the Fe uptake tremendously. Beaufils (1955) reported that Cu played an important role in the K absorption by the Hevea tree and that there was some relationship between Cu and K concentrations in the latex.

No work has been reported on the content and the availability of Cu in Malaysian soils used for Hevea cultivation. However, a Cu deficiency would usually be expected for Hevea grown on soils rich in organic matter, particularly peat soils found in the coastal areas of Malaysia.

Zinc. Zinc is an essential component of a variety of dehydrogenases, proteinases, and peptidases (Valle and Wacker, 1970). In Hevea seedlings, Zn deficient leaflets were characterized by a hook or claw appearance and overall growth was stunted (Bolle-Jones and Hilton, 1956). Zinc deficiency in Hevea seedlings was reported to be a predisposing condition for the infection of Oidium hevea, a fungus disease (Bolle-Jones, 1956). Anatomical study showed that Zn deficiency during the seedling stage caused a significant reduction in the number of latex vessels (Samsidar et al., 1975), which could affect productivity during the maturity period.

The availability of Zn in soils used for Hevea cultivation is not known, but Malaysian soils are generally acidic and nutritional problems related to Zn on Hevea trees are rarely reported. Bolle-Jones (1957b) demonstrated that Zn deficient laminae in Hevea seedlings contained 12 to 15 ppm Zn while healthy laminae contained 16 to 21 ppm or more. He also observed that a deficiency of Zn was accompanied by accumulation of Fe and Mn in the shoot tissues.

Manganese. Manganese is associated with chlorophyll formations and in respiratory enzymes (Cheniae, 1970). Manganese deficiency in Hevea seedlings has been reported to retard growth (Bolle-Jones, 1956) and also reduced the number of latex vessels (Samsidar et al., 1975).

The highly acidic nature of Malaysian soils would be expected to favor Mn availability; however, Akhurst (1933) reported that total Mn content was low for many of these soils. Widespread occurrence of Mn deficiency in both mature and immature Hevea has been observed, especially on sandy soils (RRIM, 1961). Shorrocks and Watson (1961) reported that two broadcast applications of 114 g MnSO_4 per tree was the minimum treatment required to improve the Mn status of trees affected by moderate to severe Mn deficiency. Later, Pushparajah (1969) found that even a single application of 85 g MnSO_4 per tree on a Rengam sandy loam could remedy deficiency and cause a positive response in girth. Bolle-Jones (1957c) demonstrated that Mn deficiency could also be induced by high levels of Mg in Hevea seedlings when the Mn content was low. Manganese deficiency would likely occur when the Mn concentrations in Hevea laminae fall below 45 ppm.

Boron. Boron is essential in plant auxin metabolism. Boron deficiency in Hevea plants is indicated by marked necrosis of the pith cells and heavy deposition of Ca oxalate crystals in the pith and bark (RRIM, 1956). Bolle-Jones (1954a) reported that laminae taken from B deficient Hevea seedlings contained 9 to 10 ppm B. He also stated that Hevea has a low requirement for B but retains the ability to withstand high internal concentrations of B. Later Shorrocks (1964) reported that applications of borax at 28 g per tree on one year old seedlings resulted

in extensive tip and marginal scorching of the leaves which contained 140-150 ppm B and appeared to be a symptom of B toxicity. He also observed B toxicity symptoms on Hevea growing on coastal alluvial clays and granite derived soils.

Iron and aluminum. Iron deficiency in Hevea resulted in a reduced chlorophyll content (Bolle-Jones, 1954a). Bolle-Jones (1954a and 1957c) reported that Fe deficiency was related to a low K level. A high Mn:Fe ratio could also induce Fe deficiency in Hevea seedlings. No information on the nutritional requirements of Fe is available but interactions with other nutrients appear to be more important than total supply.

The effects of Al on Hevea are not known. Like most tropical soils where Hevea is grown, Malaysian soils are known to have high Al and Fe contents (Middleton, 1965), and it is assumed that Hevea is relatively tolerant of high levels of active Fe and Al in the soil.

MATERIALS AND METHODS

Location of Sampling Sites

In the first experiment, mineral contents in soils, Hevea tissues, and the relationships between these two variables were studied. The experiment was conducted on thirteen estates located in the west coast areas of peninsular Malaysia (Fig. 1). Nine soil series most commonly used for Hevea production in the peninsula were selected for the experiment and on these soils high yielding clones were planted (Table 1). These soils were derived from different parent materials and classified under three major soil orders (Table 2). They also represented five soil suitability classes (Table 3). The clay mineralogy of these soils is shown in Table 4. Soil, leaf, bark, and bark-scrap rubber samples were taken from each location for analysis.

In the second experiment dealing with mineral nutrient distributions within the soil profiles, samples were collected from the same estates and locations described above. In addition, profile samples were collected from nine more estates representing five supplemental locations, as shown in Table 5. These sites represented the same soil series sampled in the first experiment; however, no attempt was made to collect Hevea tissues from these sites.

Table 1. Location, soils, clones, and planting dates at sites selected for sampling in first experiment.

Mapping key [†]	Estate	Location	Soil series	Hevea clone	Date planted
1.	Kim Hiock	Masai, Johore	Harimau	RRIM 600	1964
2.	Southern Malay	Simpang Rengam, Johore	Durian	RRIM 600	1964
3.	Ayer Manis	Muar, Johore	Subang	RRIM 600	1964
4.	Pajam	Mantin, Negeri Sembilan	Rengam	RRIM 600	1964
5.	Sungei Buloh	Bukit Rotan, Selangor	Selangor	RRIM 600	1963
6.	Kampar	Kampar, Perak	Holyrood	PB 5/51	1961
7.	Dovenby	Sungei Siput, Perak	Holyrood	RRIM 605	1961
	Dovenby	Sungei Siput, Perak	Holyrood	GT 1	1961
8.	Changkat Bruas	Bruas, Perak	Holyrood	RRIM 600	1965
9.	Pondoland	Pondok Tanjong, Perak	Munchong	RRIM 600	1966
10.	Eagle Hurst	Pondok Tanjong, Perak	Munchong	PB 5/51	1962
11.	Selama	Serdang, Kedah	Munchong	GT 1	1964
12.	Bukit Sembilan	Kuala Ketil, Kedah	Munchong	RRIM 600	1962
	Bukit Sembilan	Kuala Ketil, Kedah	Munchong	RRIM 605	1962
	Bukit Sembilan	Kuala Ketil, Kedah	Melaka	RRIM 600	1962
13.	Tanjong Pau	Jitra, Kedah	Serdang	RRIM 600	1965

[†]See Fig. 1.

Table 2. Classification and parent materials of nine Malaysian soils used for Hevea production (Rubber Research Institute of Malaysia, 1974).

Soil order	Sub-group	Family	Soil series	Parent materials
Inceptisols	Oxic Humitropept	Coarse loamy, siliceous, acid, isohyperthermic	Subang	Organic enriched alluvial deposits over compact sands
	Typic Sulfaquept	Fine loamy, mixed, acid, isohyperthermic	Selangor	Marine alluvium
	Oxic Dystropept	Fine loamy, siliceous, isohyperthermic	Holyrood	Subrecent riverine alluvium
	Typic Paleudult	Clayey, kaolinitic, isohyperthermic	Harimau	Older alluvium
Ultisols	Typic Paleudult	Clayey, kaolinitic, isohyperthermic	Rengam	Granite
	Typic Paleudult	Fine loamy, siliceous, isohyperthermic	Serdang	Sandstone
	Typic Plinthudult	Clayey, mixed, isohyperthermic	Durian	Argillaceous shale
	Tropeptic HapTorthox	Clayey, kaolinitic, isohyperthermic	Munchong	Argillaceous shale
Oxisols	Plinthic HapTorthox	Clayey-skeletal, kaolinitic, isohyperthermic	Metaka	Argillaceous shale

Table 3. Categorization of selected soils as to soil suitability class for Hevea production (Chan and Pushparajah, 1972).

Soil series	Soil suitability class	Yield category	Average or expected yield
			kg/ha/yr
Munchong	Ia	High	> 1350
Rengam	Ib	High	1250-1350
Harimau	IIa	Above-average	1150-1250
Subang	IIb	Above-average	1150-1250
Serdang	III	Average	1050-1150
Holyrood	III	Average	1050-1150
Durian	IV	Below-average	950-1050
Melaka	IV	Below-average	950-1050
Selangor	V	Low	< 950

Table 4. Clay mineralogy of nine Malaysian soils investigated (Noordin, 1977).

Soil series	Quartz	Kaolinite	Goethite	Gibbsite	Illite	Vermiculite	Montmorillonite	Mica	Chlorite
Subang									
Selangor		X			X		XX	X	
Holyrood		XXX			X			X	
Harlmau		XXX	X						
Rengam	X	XXX		T	X				X
Serdang		XX	X		T	X [†]			
Durian	X	XX	X		X			X	
Munchong		XX	XX	X					
Melaka		XXX	XX	XX					

NA--Information not available

T--Trace (5%)

X--Low 5-20%

XX--Medium 20-50%

XXX--High 50%

[†]Al--Vermiculite

Table 5. Location of soil series sites selected for profile study in second experiment.

Location number†	Estate	Location	Soil series	Profiles sampled	Subsamples per profile
1.	Kim Hiock	Masai, Johore	Harimau	3	4
	Permas	Masai, Johore	Harimau	1	4
	Sungei Tiram	Masai, Johore	Harimau	1	4
2.	Southern Malay	Simpang Rengam, Johore	Durian	1	5
3.	Ayer Manis	Muar, Johore	Subang	2	3 & 4
	FELDA† Lenga	Muar, Johore	Durian	1	4
4.	Pajam	Mantin, Negeri Sembilan	Rengam	2	4 & 3
5.	Sungei Buloh	Bukit Rotan, Selangor	Selangor	2	3 & 4
6.	Kampar	Kampar, Perak	Holyrood	1	5
7.	Dovenby	Sungei Siput, Perak	Holyrood	2	4
8.	Changkat Bruas	Bruas, Perak	Holyrood	2	4
9.	Pondoland	Taiping, Perak	Munchong	1	3
10.	Eagle Hurst	Taiping, Perak	Munchong	1	4
11.	Selama	Selama, Kedah	Melaka	1	3
12.	Bukit Sembilan	Kuala Ketil, Kedah	Munchong	2	3 & 5
	Bukit Sembilan	Kuala Ketil, Kedah	Melaka	1	4

Table 5. (continued)

Location number [†]	Estate	Location	Soil series	Profiles sampled	Subsamples per profile
13.	Tanjong Pau	Jitra, Kedah	Serdang	2	3 & 4
14.	Foh Cheng	Kota Tinggi, Johore	Rengam	1	5
15.	Malay Rompin	Bahau, Negeri Sembilan	Durian	1	5
16.	FELDA Kelamah	Gemas, Negeri Sembilan	Durian	1	5
	FELDA Kelamah	Gemas, Negeri Sembilan	Melaka	1	4
17.	FELDA Palong	Gemas, Negeri Sembilan	Durian	1	4
	RRIES [§]	Sungei Buloh, Selangor	Subang	1	4
	RRIES	Sungei Buloh, Selangor	Rengam	1	5
	RRIES	Sungei Buloh, Selangor	Melaka	1	3
	RRIES	Sungei Buloh, Selangor	Serdang	1	5
18.	Sungai Rambai	Batang Berjuntai, Selangor	Selangor	1	5

[†]See Fig. 1.[‡]FELDA--Federal Land Development Authority.[§]RRIES---Rubber Research Institute Experimental Station.

Cultural Practices of Plantations

The plantations that were selected for this study consisted of mature, about fifteen years old, Hevea trees in commercial production. Under current plantation practices, young Hevea trees come into production at the age of five to seven years, depending on the clonal characteristics, soils, and the agronomic management inputs. During the initial field establishment of young Hevea, the standard practice is to apply rock phosphate at 114 g per planting hole mixed with the top 15 cm soil. Regular dressings of mixed fertilizers, which usually contain N, P, K, and Mg, are applied broadcast in a 30-40 cm diameter circle around the plant during the early stages of growth. Where a cover of native legumes is maintained in the inter-row rock phosphate is applied in this area.

After the fourth year of growth, fertilizer mixtures at higher rates of N, P, K, and Mg are usually applied in a strip covering an area parallel to the tree-row and extending about 60-300 cm from the tree-row, the inter-row. The preferred method of application is usually to broadcast the fertilizers on flat areas and terraces. However in certain situations, especially on terraced slopes, fertilizers are "pocketed," i.e., placed in random holes about 3 cm depth along the tree-rows, so as to reduce losses by leaching or surface runoff. Plantations involved in this study were under many different managements. Available fertilization histories showed wide variations in cultural practices with regard to methods of application and frequency of fertilization.

Collection of Samples

Leaves, Bark, and Bark-Scrap Rubber

Sample collections were conducted during the months of August to October of 1976 and 1977. Each clone sample was represented by three blocks of thirty trees and each block was sampled as follows:

Four high-yielding Hevea clones, namely, RRIM 600, RRIM 605, PB 5/51, and GT 1, which have been cultivated on the nine soil series (Table 1) were selected for this study. Representative leaf samples from recently matured low shade leaves were taken from trees grown on each soil series. During the same operation, fresh bark shavings were obtained from the same trees from which leaf samples were collected (bark-scrap rubber was separated from this bark when the latter was ground for chemical analysis). Leaf and bark samples were transported to the laboratory of the Rubber Research Institute of Malaysia (RRIM), oven-dried at 65 C, and packed for shipment to the United States in wooden boxes. They were air-shipped to the Soil Science Department laboratory at the University of Florida, Gainesville. Upon arrival the samples were dried overnight at 70 C, then ground in a stainless steel Wiley mill to pass a 20-mesh screen. A sample-splitter was used to insure homogeneously mixed plant samples.

Soils

Soil core samples were taken for the first experiment at 0-15 cm and 15-30 cm at two sampling locations: 1) along tree-rows and 2) between tree-rows (inter-row). A total of twelve samples was collected from each

soil series from each estate; three samples from each sampling location and depth.

Soil core samples were taken with a stainless steel tube. Each composite sample (± 300 g) consisted of ten random cores collected from the same area and representative of the soil series. Soil samples were placed in marked plastic bags. At the RRIM laboratory these samples were air-dried, placed in plastic bags, and packed in wooden boxes. Shipment of samples to the United States followed the same procedure as described previously for the plant samples.

In the second experiment, a study of the distribution of mineral contents within the soil profile, soil samples were taken from the inter-row at various depths according to their genetic horizons as determined by color or textural changes. Procedures in soil sampling were the same as described previously. Nine soil series from twenty-two estates were included in this study (Table 5).

Soil Analyses

Air dried soil samples were prepared for analysis by screening through a 3-mm stainless steel sieve and using a sample-splitter to obtain homogenous samples. Soil pH was measured in distilled water and N KCl with a glass electrode in 1:2, soil to solution suspensions. Delta pH (Δ pH) was computed as $pH(H_2O) - pH(KCl)$. Soil organic matter was determined by wet-combustion with $K_2Cr_2O_7$ as proposed by Walkley and Black (1934). The calculation used for percent carbon was based on a value of 75% of the organic carbon being oxidized. The conventional factor of 1.724 was used as a conversion factor of carbon to organic matter (Allison, 1965).

Exchangeable Ca, Mg, Al, acidity, and effective cation exchange capacity (ECEC) were determined by \underline{N} KCl soil extraction. The extract was made with 5 g of soil and 25 ml of \underline{N} KCl placed in a 125-ml Erlenmeyer flask and shaken intermittently for 30 minutes. The soil suspension was filtered by gravity through Whatman No. 44 filter paper. Small portions, ca. 5 ml, of \underline{N} KCl solution were leached through the soil over a period of 2 hours, until 50 ml of filtrate had been collected. The filtrate was mixed thoroughly, and an aliquot of this extract was used for Ca and Mg determinations by atomic absorption spectrophotometry (Perkin Elmer 603). Another 25 ml aliquot was used for exchangeable acidity and Al determination by the following procedures: 25 ml of the solution was placed in a 125-ml Erlenmeyer flask, 5 drops of phenolphthalein indicator was added and the solution was titrated with 0.1 \underline{N} NaOH to a permanent pink end-point with alternate stirring and standing. The total amount of base used in this titration is equivalent to the total exchangeable acidity (H and Al) of the soil. To bring the solution back to the colorless end-point, a drop of 0.1 \underline{N} HCl was added. Then 10 ml of 4% NaF is added and if Al is present the solution will again change to a pink color. In which case, the solution was again titrated to a colorless end-point with 0.1 \underline{N} HCl, while constantly stirring. The milliequivalents of acid used in this titration were computed as a measure of exchangeable Al. The amount of exchangeable H was obtained by the difference between the total exchangeable acidity and exchangeable Al (Yuan, 1959). The ECEC is the sum of the exchangeable Ca, Mg, H, and Al (Coleman and Thomas, 1967). Percentage Al saturation was calculated based on exchangeable Al in relation to ECEC (Kamprath, 1970). Different

estimates of nutrients available to plants were obtained by extracting the soils by three different procedures.

Double-Acid (DA) Reagent

The DA reagent was a solution containing 0.05 N HCl and 0.025 N H₂SO₄ (Mehlich, 1953). Five grams of air-dried soil was placed in a 125-ml Erlenmeyer flask and 20 ml of the reagent added. Each flask was covered with Parafilm and secured upright on a horizontal Eberbach shaker with a stroke length of 4.5 cm and a speed of 140 strokes per minute. After one hour of shaking, the suspensions were filtered by gravity through Whatman No. 44 filter paper. Filtrates were analyzed colorimetrically for P by the ascorbic acid-reduced molybdophosphoric blue method (Watanabe and Olsen, 1965), for K by flame photometry, and for Ca, Mg, Cu, Zn, Mn, Fe, and Al by atomic absorption spectrophotometry (Perkin-Elmer 603).

EDTA-TEA Reagent

The EDTA-TEA reagent (Lam and Gammon, 1976) was prepared to contain 0.005 M ethylenediaminetetraacetic acid (EDTA) (C₁₀H₁₄O₈N₂Na₂·2H₂O), 0.01 M CaCl₂, 0.1 M triethanolamine (TEA) (HOCH₂CH₂)₃, and the mixture adjusted to pH 7.30 with NaOH. Ten grams of air-dried soil was placed in a 125-ml Erlenmeyer flask, and 20 ml of the reagent added. The extracting procedures and elemental determinations were similar to those previously described for the DA method.

5 N HCl Reagent

This reagent was prepared by diluting concentrated HCl to 5 N HCl. Five grams of air-dried soil was placed in a 125-ml Erlenmeyer flask and 20 ml of the reagent added. The extracting procedures and elemental determinations were similar to those described previously with the following changes. The shaking time was reduced to 15 minutes and the filtrates were diluted to about N HCl with distilled water prior to initiating the analytical procedures.

All B determinations were carried out in B-free containers. Boron was colorimetrically determined by azomethine-H reagent (Wolf, 1971) after it was extracted from the soil with hot water. A 12.5 g sample of air-dried soil was placed in a 100-ml beaker together with 0.5 cm³ of activated charcoal (Darco Activated Carbon Grade 60) to decolorize the soil extract. Then 25 ml of hot water was added to the soil and the suspension stirred thoroughly. The mixture was boiled for 15 minutes and then filtered through Whatman No. 2 filter paper collecting the filtrate in a plastic bottle. Four milliliters of soil extract was pipetted into a glass bottle and 1 ml each of buffer masking reagent (containing Na₂-EDTA dissolved in glacial acetic acid) and azomethine-H reagent added. The solution was mixed well and then permitted to stand for 1 hour to develop a stable color. The color was then measured spectrophotometrically by using Model 20 Bausch and Lomb colorimeter at 420 nm.

Plant Analyses

Leaf, bark, and bark-scrap rubber samples were redried in an oven at 65 C for overnight, prior to weighing for laboratory analyses. A 5 g

sample was placed in a 150-ml Pyrex glass beaker and ashed in a Type 1600 Thermolyne muffle furnace at 475 C for 4 hours (Issac and Jones, 1972). The dry ashed sample was treated with 20 ml 5 N HCl and 5 ml 16 N HNO₃ mixture which was then evaporated to dryness on a hot plate. Any remaining carbon was removed from the sample by adding 5 ml 30% H₂O₂ and evaporating on a hot plate. This step was repeated if the sample still contained more than a trace of carbon. The sample was dissolved in 10 ml 5 N HCl, evaporated to dryness and the dry residue heated to dehydrate silica. The residue was treated with 5 ml 0.1 N HCl, warmed to dissolve salts, and filtered through a Nalgene funnel, using No. 42 Whatman filter paper and made up to a final volume of 50 ml. The filtrate was analyzed for Ca, Mg, Cu, Zn, Mn, Fe, and Al by atomic absorption spectrophotometry (Perkin Elmer 603). Potassium was determined by Beckman flame spectrophotometer (Model B) and P was determined colorimetrically by the ascorbic acid-reduced molybdophosphoric blue method (Watanabe and Olsen, 1965) using a Model 20, Bausch and Lomb colorimeter at 880 nm.

Boron was determined on separate samples by the azomethine-H reagent method (Wolf, 1971). A 1 g plant sample was placed in a quartz crucible and dry ashed in a muffle-furnace in which the temperature was slowly increased to 450 C following which, ashing was continued for six hours. After cooling, the ashed sample was dissolved in 10 ml 0.1 N HCl and filtered through a Whatman No. 2 filter paper. The filtrate was collected in a 50-ml volumetric flask. The filtrate was thoroughly mixed by vigorous shaking and 2 ml of the extract pipetted into a glass vial. A 4 ml buffer-masking solution, containing Na₂-EDTA dissolved in glacial acetic acid, was added to the extract followed by addition of 4 ml

azomethine-H reagent to develop the color. After standing 1 hour, B was determined by the same procedure as described previously.

Statistical Analyses

All soil data, except those from profile studies, were analyzed according to soil series, row, depth, and extractant. The Hevea tissue (leaves, bark, and bark-scrap rubber) data were analyzed according to series, clone, and year.

In each case, the statistical model used was a split-split-split plot for soil and randomized block with factorials for Hevea tissues (Steel and Torrie, 1960). In all cases soil series were the whole plots, with the effects of row, depth, extractant, clone, and year treated as subplots. Duncan's New Multiple Range Test (DNMRT) was used to compare the means.

Correlations were determined with all the possible combinations between mineral contents in nine soil series (taken at two depths and two row locations, and extracted by three extractants) and the three Hevea tissues. Correlations between mineral contents within each Hevea tissue were also sought. Statistical Analysis System (Barr et al., 1976) was used and computer processing of the data was done at the North-East Regional Data Center (NERDC) of the University of Florida.

RESULTS AND DISCUSSION

Chemical Characteristics of Soils

Differences in chemical properties among soil series and between soil depths are normally expected. In an effort to determine sites for soil sampling that would most closely correlate with mineral levels in the plant, soils were sampled in the tree-row and in the inter-row at each site. In each case separate samples were taken at 0-15 and 15-30 cm depths. It was anticipated that differences between tree-row and inter-row would result from cultural practices, primarily from the kinds, quantities, and the placement of these fertilizer materials. As the data were accumulated, it became evident that cultural practices varied from site to site not only in the kinds and rates of fertilization but also in the placement. Hence it must be realized that although trends may be established by summarized data, individual sites may deviate from these trends.

Data on important chemical properties of the soils studies are summarized in Table 6 and their analysis of variance are shown in Appendix Table 45. The soil series are listed in order of decreasing latex yields as reported from the plantations surveyed in this investigation, except for the Rengam series where yield data were not available (Table 24).

Table 6. Summary of chemical properties of nine Malaysian soils used for Hevea production.[†]

Soil series	pH		Δ pH	Organic matter	N KCl exchangeable				ECEC	Al saturation [‡]
	H ₂ O	N KCl			Ca	Mg	Al	acidity		
				%	-----meq/100 g-----					%
Durian	4.47a [§]	3.58a	-0.89a	1.92c	0.17b	0.09cd	2.40b	2.87b	3.13b	77a
Serdang	4.96a	3.95a	-1.01a	0.94c	0.39b	0.12c	0.53c	1.08cd	1.58c	34a
Munchong	4.51a	3.89a	-0.62a	1.80c	0.12b	0.06d	0.90c	1.48c	1.65c	55a
Melaka	4.55a	3.86a	-0.69a	1.50c	0.19b	0.06d	0.91c	1.51c	1.76c	52a
Subang	4.00a	3.57a	-0.43a	22.87a	0.46ab	0.20b	2.39b	3.21b	3.87b	62a
Hollyrood	4.67a	4.08a	-0.59a	1.19c	0.37b	0.06d	0.43c	0.68d	1.10c	39a
Selangor	4.36a	3.52a	-0.85a	7.07b	1.12a	0.90a	5.92a	6.91a	8.93a	66a
Harimau	4.70a	3.99a	-0.70a	1.80c	0.17b	0.08cd	0.49c	1.23cd	1.47c	33a
Rengam	4.42a	3.94a	-0.48a	2.20c	0.20b	0.07cd	0.74c	1.25cd	1.52c	49a

[†]Each figure represents average values of 0-15 and 15-30 cm horizon of samples taken in the row (tree-row) and between tree-row (inter-row).

[‡]Al saturation = Exchangeable Al/ECEC x 100.

[§]Means within column followed by same letter are not significantly different at 0.05 level by DMRT.

Soil pH (in H₂O)

These soils were strongly acidic with pH values ranging from 3.93 to 5.00. The differences in acidity appeared to be related to the organic matter content as evident in soils of the Subang and Serdang series where pH decreased appreciably with an increase in organic matter content.

Soil acidity in the tree-row did not differ significantly from the inter-row (Table 7) despite the fact that the inter-row represents the area usually receiving the bulk of the fertilizer after the tree reaches maturity.

Soil acidity varied significantly with depths and within depths between soil series, as shown in Tables 9 and 10, respectively. The soil pH was slightly higher in the top 0-15 cm between soil series and ranged from 4.07 to 4.93, while in the lower 15-30 cm it ranged from 3.93 to 5.00. The difference in the soil pH between the two depths was generally related to greater quantities of exchangeable Al and the associated higher percentages of Al saturation rather than the organic matter.

Soil pH (in KCl)

In none of the soils were the values obtained for pH in N KCl greater than those in water (Table 6). The Δ pH (difference between pH in KCl and pH in water) ranged from -0.43 to -1.01 pH units, indicating the predominance of net negative charges in all these soils. There was no statistical difference in soil pH in N KCl between the tree-row and inter-row nor within the row among soil series (Tables 7 and 10).

Table 7. Differences in soil chemical characteristics of nine Malaysian soils used for Hevea production as influenced primarily by location of sampling.

Depth cm	pH		Δ pH	Organic matter	N KCl exchangeable				ECEC	Al saturation [†] %
	H ₂ O	N KCl			Ca	Mg	Al	acidity		
				%	-----meq/100 g-----					
					<u>Tree-row</u>					
0-15	4.52	3.86	-0.66	3.49	0.28	0.12	1.15	1.69	2.07	56
15-30	4.49	3.87	-0.62	2.76	0.24	0.12	1.38	1.98	2.34	59
Average	4.51a [‡]	3.87a	-0.64a	3.12b	0.26b	0.12b	1.27a	1.83a	2.22a	57a
					<u>Inter-row</u>					
0-15	4.62	3.90	-0.72	3.68	0.38	0.14	1.04	1.53	2.05	51
15-30	4.54	3.90	-0.64	3.07	0.24	0.13	1.32	1.83	2.20	60
Average	4.58a	3.90a	-0.68a	3.38a	0.31a	0.14a	1.18b	1.68b	2.13b	55a

[†]Al saturation = Exchangeable Al/ECEC x 100.

[‡]Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

Table 8. Chemical properties of nine Malaysian soils used for Hevea production as related to location of sampling.[†]

Soil series	pH		Δ pH	Organic matter	N KCl exchangeable			ECEC	Al saturation ‡	
	H ₂ O	N KCl			Ca	Mg	Al			acidity
	%				-----meq/100 g-----					%
					Tree-row					
Durian	4.33a ^s	3.54a	-0.80a	1.99d	0.19de	0.09d	2.43b	2.89c	3.17c	77a
Serdang	4.80a	3.91a	-0.89a	0.86g	0.47b	0.12c	0.63d	1.09e	1.68d	38a
Munchong	4.48a	3.88a	-0.60a	1.73d	0.13e	0.06de	0.90c	1.53d	1.71d	53a
Melaka	4.60a	3.89a	-0.71a	1.34ef	0.21d	0.06de	0.90c	1.48d	1.75d	51a
Subang	3.98a	3.56a	-0.42a	22.77a	0.46b	0.20b	2.42b	3.15b	3.82b	63a
Holyrood	4.68a	4.05a	-0.62a	1.14fg	0.39c	0.05e	0.44e	0.70f	1.15e	38a
Selangor	4.32a	3.47a	-0.85a	5.63b	0.59a	0.75a	6.43a	7.44a	8.79a	73a
Harimau	4.67a	4.04a	-0.64a	1.57de	0.17de	0.07de	0.43e	1.43d	1.67d	26a
Rengam	4.33a	3.88a	-0.45a	2.57c	0.18de	0.07de	0.78cd	1.42d	1.67d	47a

Table 8. (Continued)

Soil series	pH		Δ pH	Organic matter	N KCl exchangeable				ECEC	Al saturation [†]
	H ₂ O	N KCl			Ca	Mg	Al	acidity		
					-----meq/100 g-----					%
					<u>Inter-row</u>					
Durian	4.61a [§]	3.63a	-0.98a	1.85c	0.14ef	0.10cd	2.37b	2.85c	3.08c	77a
Serdang	5.13a	4.00a	-1.13a	1.02d	0.30cd	0.11c	0.43e	1.07e	1.47ef	29a
Munchong	4.55a	3.90a	-0.65a	1.86c	0.10f	0.06f	0.90c	1.42d	1.58e	57a
Melaka	4.51a	3.84a	-0.67a	1.66c	0.17e	0.07ef	0.93c	1.53d	1.76d	53a
Subang	4.02a	3.58a	-0.44a	22.96a	0.45b	0.20b	2.36b	3.26b	3.91b	60a
Hollyrood	4.68a	4.10a	-0.57a	1.23d	0.34c	0.06f	0.41e	0.66f	1.05g	39a
Selangor	4.41a	3.57a	-0.84a	8.51b	1.64a	1.05a	5.40a	6.39a	9.08a	59a
Harimau	4.72a	3.95a	-0.77a	2.03c	0.17e	0.08de	0.54de	1.02e	1.27f	43a
Rengam	4.51a	4.01a	-0.50a	1.83c	0.22de	0.07ef	0.70d	1.08e	1.37f	51a

[†]Each figure represents average of 0-15 and 15-30 cm horizon.[‡]Al saturation = Exchangeable Al/ECEC x 100.[§]Means within column segment followed by same letter are not significantly different at 0.05 level by DNMR.

Table 9. Differences in soil chemical characteristics of nine Malaysian soils used for Hevea production as influenced primarily by depth of sampling.

Row	pH		Δ pH	Organic matter	N KCl exchangeable				ECEC	Al saturation [†]
	H ₂ O	N KCl			Ca	Mg	Al	acidity		
				%	-----meq/100 g-----					%
					0-15 cm					
Tree-row	4.52	3.86	-0.66	3.49	0.28	0.12	1.15	1.69	2.09	55
Inter-row	4.62	3.90	-0.72	3.68	0.38	0.14	1.04	1.53	2.05	51
Average	4.57a [‡]	3.88a	-0.69a	3.58a	0.33a	0.13a	1.10b	1.61b	2.07b	53b
					15-30 cm					
Tree-row	4.49	3.87	-0.62	2.76	0.24	0.12	1.38	1.98	2.34	59
Inter-row	4.54	3.90	-0.64	3.07	0.24	0.13	1.32	1.83	2.20	60
Average	4.52b	3.89a	-0.63a	2.92b	0.24b	0.12a	1.35a	1.90a	2.27a	59a

[†] Al saturation = Exchangeable Al/ECEC x 100.

[‡] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMRT.

Table 10. Chemical properties of nine Malaysian soils used for Hevea production as related to depth of sampling.[†]

Soil series	pH		Δ pH	Organic matter	N KCl exchangeable			ECEC	Al saturation [‡]	
	H ₂ O	N KCl			Ca	Mg	Al			
	-----meq/100 g-----									
					0-15 cm					
Durian	4.60bc ^s	3.62d	-0.98a	2.33cd	0.18d	0.10c	2.18b	2.66b	2.95c	74a
Serdang	4.93a	4.00ab	-0.93a	1.00f	0.50b	0.12c	0.51d	0.98d	1.60d	32a
Munchong	4.51c	3.87c	-0.64a	2.04cd	0.11d	0.06c	0.86c	1.44c	1.61d	53a
Melaka	4.52c	3.96c	-0.66a	1.61def	0.17d	0.06c	0.83c	1.43c	1.67d	50a
Subang	4.07d	3.61d	-0.46a	21.75a	0.40b	0.20b	2.11b	2.89b	3.48b	61a
Holyrood	4.73b	4.05a	-0.68a	1.53ef	0.40b	0.07c	0.41d	0.65e	1.12e	37a
Selangor	4.49c	3.61d	-0.89a	9.80b	1.55a	0.84a	4.73a	5.45a	7.84a	60a
Harimau	4.65bc	3.96b	-0.69a	2.03cde	0.17d	0.08c	0.48d	1.23c	1.48d	32a
Rengam	4.45c	3.93bc	-0.53a	2.52c	0.21cd	0.08c	0.73c	1.36c	1.65d	44a

Table 10. (continued)

Soil series	pH		Δ pH	Organic matter	N KCl exchangeable			ECEC	Al saturation [†]	
	H ₂ O	N KCl			Ca	Mg	Al			
	-----meq/100 g-----									
				%	-----meq/100 g-----					%
					15-30 cm					
Durian	4.34d [§]	3.55d	-0.80a	1.52cd	0.15c	0.08c	2.62b	3.07c	3.31c	79a
Serdang	5.00a	3.91c	-1.09a	0.88de	0.27bc	0.11c	0.55e	1.18e	1.55def	35a
Munchong	4.52c	3.91c	-0.61a	1.55cd	0.12c	0.05c	0.93c	1.51d	1.68de	55a
Melaka	4.58bc	3.87c	-0.72a	1.39cde	0.21bc	0.07c	0.99c	1.58d	1.85d	54a
Subang	3.93e	3.53d	-0.40a	23.98a	0.52a	0.20b	2.67b	3.52b	4.24b	63a
Hollyrood	4.61b	4.10a	-0.52a	0.84e	0.33b	0.04c	0.45e	0.70f	1.08g	42a
Selangor	4.23d	3.43e	-0.81a	4.34b	0.68a	0.97a	7.10a	8.38a	10.02a	71a
Harimau	4.74b	4.03ab	-0.72a	1.57cd	0.17bc	0.07c	0.49e	1.22e	1.46ef	34a
Rengam	4.39cd	3.96bc	-0.43a	1.89c	0.19bc	0.06c	0.75d	1.13e	1.38f	54a

[†]Each figure represents average of tree- and inter-row.[‡]Al saturation = Exchangeable Al/ECEC x 100.[§]Means within column segment followed by same letter are not significantly different at 0.05 level by DNMR.

Soil pH in N KCl varied significantly with depth but not within depths among soil series (Tables 9 and 10). The Δ pH was relatively higher in the top 0-15 cm than in the lower 15-30 cm, averaging -0.69 and -0.63, respectively. The net charges from the organic matter complex which were higher in the surface soils probably contributed to offset any net positive charge that comes from the mineral fractions, which may also explain the non-existence of a positive Δ pH in these particular soils.

Organic Matter Content

Among soil series, organic matter content varied significantly from a low 0.94% to as high as 22.87% (Table 6). However, the majority of the soil series have organic matter contents within the range of 1.19 to 2.20%. The high organic matter content found in the Subang series was not unexpected because these soils were derived from organic enriched alluvial deposits (Table 3). Both the Subang and Selangor series require drainage before they can be used for Hevea production.

As indicated in Table 7, organic matter content was significantly higher in the inter-row than the tree-row areas. These differences may result from the greater accumulations of leaves and litterfall within the inter-row since tree-canopies from both sides are concentrated over the inter-rows. However, among individual soil series, organic matter content was not always higher in the inter-row soil. In all series, organic matter content was significantly higher in the 0-15 cm than the 15-30 cm horizon (Table 9).

Exchangeable Calcium

With the exception of Selangor series (1.12 meq/100 g Ca), the majority of the soils were relatively low in exchangeable Ca with values ranging from 0.12 to 0.46 meq/100 g (Table 6). While in most of these soils 1:1 type of clay minerals predominated, the 2:1 clay minerals in Selangor series evidently contributed to the higher retention of exchangeable bases such as Ca. The high organic matter content of the Subang soil evidently helped in retention of a higher level of exchangeable Ca in that soil.

Although exchangeable Ca was just slightly higher in inter-row than tree-row areas, with values of 0.31 and 0.28 meq/100 g, respectively, the differences were significant (Table 7). The higher organic matter content in the inter-row as well as the application of rock phosphate and other Ca-containing fertilizers in this area may result in the higher Ca levels. Variation in exchangeable Ca among soil series did not always favor higher Ca in the inter-row. This may have been a result of different methods of fertilizer application or some residual effects of fertilizer which had been applied close to the trees during the first few years of growth.

Exchangeable Ca was significantly higher in the surface soils (0-15 cm) than at 15-30 cm depth (Table 9). Differences in exchangeable Ca among soil series at each depth were also significant (Table 10). Exchangeable Ca varied from 0.11 to 1.55 meq/100 g in the top 0-15 cm and a narrower range, 0.12 to 0.68 meq/100 g was found at the lower depth. The higher exchangeable Ca in the surface layer may be related to the frequent applications of rock phosphate and other Ca-containing fertilizers.

Exchangeable Magnesium

With the exception of soil from Selangor series, the soils were low in exchangeable Mg (Table 6). The intermediate level of exchangeable Mg in Subang soils was probably related to the organic matter content. The high organic matter and 2:1 clay favored the retention of exchangeable Mg in the Selangor series while the other soils were lower in both organic matter and 2:1 clay contents.

Exchangeable Mg was significantly higher in the inter-row than the tree-row. A similar trend was also shown for the exchangeable Mg among most of the soil series (Table 8). The difference in the exchangeable Mg values between the two rows could result from the placement of dolomite or fertilizers which are usually applied over the inter-row area. Exchangeable Mg between the two depths, 0-15 cm and 15-30 cm, was not significantly different (Table 9). However, at each depth and regardless of row among soil series, exchangeable Mg varies significantly (Table 10).

Exchangeable Aluminum

Following a characteristic that is common in most soils from the humid tropics, most of the soils contain considerable quantities of exchangeable Al (Table 6). Exchangeable Al varied from 0.43 to 5.92 meq/100 g among the soil series. The high level of exchangeable Al in some of these soils is related to the kinds and quantity of clay minerals present as well as to the extremely acid condition of the soils as represented by Selangor, Durian, and Subang series. The presence of large

quantities of exchangeable Al in acid soils has been generally known since the report of Hartwell and Pember (1918).

Exchangeable Al was significantly higher in the tree-row than the inter-row with values of 1.27 and 1.18 meq/100 g, respectively (Table 7). More acid-forming fertilizers, such as ammonium sulfate, applied in the tree-row or the higher organic matter content in the inter-row could account for the difference. Evans and Kamprath (1970) found that organic matter reduced the solubility of Al through stable complex formation and resulted in less soluble Al in the soil solution. Within each row among soil series, exchangeable Al also varied significantly (Table 8). It should be noted that exchangeable Al did not vary proportionally as much as exchangeable bases within the two rows among soil series. This was probably the result of the acidic condition in these soils which favored greater leaching of exchangeable bases. The levels of exchangeable Al were significantly higher in the lower 15-30 cm depth than the top 0-15 cm (Table 9). Although these differences were related to the pH (H_2O) and organic matter at the two depths, they may also reflect the effects of rock phosphate applied to the surface soil. A significant variation was also noted in the level of exchangeable Al among the soil series within each depth (Table 10).

Exchange Acidity

Exchange acidity varied significantly from one soil series to another and ranged from 0.68 to 6.91 meq/100 g (Table 6). The Holyrood series with a lower clay percentage contributed less exchangeable Al and consequently a lower level of exchange acidity. Soils of the Selangor

series showed significantly higher levels of exchange acidity with exchangeable Al contributing more than 85%. Coleman et al. (1967) found that montmorillonitic soils consistently contained higher levels of exchangeable acidity than did soils dominated by kaolinite. Exchangeable Al generally contributed a greater portion of the exchangeable acidity of soils with a high clay content.

Exchange acidity was significantly higher in tree-row than inter-row areas (Table 7). This may be related to fertilizer practices or organic matter as discussed previously. Among the soil series, exchange acidity also varied significantly and ranged from 0.70 to 7.44 meq/100 g in the tree-row and from 0.66 to 6.39 meq/100 g in the inter-row. High levels of exchange acidity were associated with high levels of exchangeable Al.

Exchange acidity was significantly higher in the 15-30 cm horizon, with a mean value of 1.90 meq/100 g compared to 1.61 for the surface. A significant variation also existed in exchange acidity at each depth among soil series.

Effective Cation Exchange Capacity

A significant variation in ECEC was observed among soil series (Table 6). The ECEC values depend largely on the total acidity including exchangeable Al, but basic cations also increase with increased ECEC as shown in Selangor, Subang, and Durian soil series. Kawaguchi and Kyuma (1969) studied the fertility status of rice soils in Malaysia; those with ECEC values of less than 5 meq/100 g were placed in the low fertility class. Using the same criteria, most of the soils in this study

would be considered to be seriously low in their ECEC. With the exception of Selangor series, these soils have an average ECEC value of less than 4 meq/100 g. According to Sanchez (1976), soils with an ECEC of less than 4 meq/100 g are considered to have been subject to severe leaching losses.

The low ECEC values for most of these soils are closely associated with the 1:1 clay mineralogy and generally low clay and organic matter contents. Because of the acidic condition of these soils, the contribution of organic matter to ECEC will be low. Matsuo (1968) reported that in Malaysian soils, 2:1 and 2:2 clay minerals contributed the most ECEC, followed by organic matter and 1:1 type clays. The ECEC values obtained for Subang and Selangor series (Table 6) were in good agreement with these findings. Selangor soil series, which contained a significant quantity of 2:1 clay minerals (Noordin, 1977), had the highest ECEC values. These values were higher than those of the Subang series whose organic matter content was about three times greater than the Selangor series.

A significantly higher ECEC for soils in the tree-row over the inter-row (Table 7) represents average long term effects of cultural practices in Hevea. This would include annual applications of N fertilizer from sulphate of ammonia which has a strongly acidifying effect, and the application of rock phosphate which has a neutralizing effect with an increase in exchangeable Ca levels. The net result for these soils was more exchangeable acidity in the tree-row contributing to a higher ECEC value while more exchangeable Ca was found in the inter-row. In the tree-row among soil series, regardless of depth, ECEC was found greatest on Selangor soils while the lowest value was noted on Holyrood

soil (Table 8). The same trend was also observed in the inter-row; however, ECEC values between the two rows differed in the two soils. The higher ECEC value for the Holyrood soil was obtained in the tree-row, whereas the Selangor series showed a greater ECEC in the inter-row. This difference could be attributed to the variation in the kind and placement of fertilizers depending on the management practices of each plantation.

Soils from the 15-30 cm horizon were significantly higher in ECEC than the 0-15 cm (Table 9). This may be related to reduced weathering in the lower horizon and hence more active exchange sites were found in the lower horizon. In the surface horizon for all soil series and in all locations, exchangeable Ca and Mg made up a larger portion of the ECEC than in the 15-30 cm horizon (Table 10).

Aluminum Saturation

Percent Al saturation among soil series, regardless of row and depth, was fairly high and quite variable (Table 6), but differences were not significant among the soils. Aluminum saturation was greater than 50% in the soils except for Serdang, Holyrood, Harimau, and Rengam series. The Serdang and Holyrood soils were relatively high in exchangeable Ca for their low ECEC whereas in Harimau and Rengam series exchangeable H occupied a large percentage of the exchange sites; thus percent Al saturation was reduced in these soils. In contrast, the Durian soil was low in exchangeable Ca, and exchangeable Al contributed more than 80% of the exchangeable acidity; hence, the Al saturation of the ECEC was very high. The intense leaching environment favors a loss

of bases and increased acidity. Addition of fertilizer salts, such as chloride and sulfate will also increase the concentration of Al in soil solution (Bhumbla and McLean, 1965; Brenes and Pearson, 1973).

Average percent Al saturation between the tree-row and inter-row, regardless of depth and soil series, was not significant (Table 7). Within each row, regardless of depth, percent Al saturation did not differ significantly among soil series (Table 8). The wide and inconsistent variations observed within each row among soils may reflect the current cultural practices, which were not the same for all plantations.

Percent Al saturation in the 15-30 cm horizon, regardless of row and soil series, was significantly higher than the surface soil (Table 9). The higher level of bases in the surface may be attributed to recent fertilization and recycling of mineral nutrients. However, within each depth, regardless of row, percent Al saturation did not vary significantly among soil series (Table 10). Neither percent Al saturation nor the quantity of exchangeable Al in the KCl extract seemed to have any effect on the latex yields reported for the soils. Kamprath (1970) indicated that optimum growth was obtained when Al saturation was less than 40% for maize, and less than 20% for soybean.

Mineral Contents of the Soils

Effect of Extractants

The overall mean values of minerals removed by the three extractants from soils, taken from tree-rows and inter-rows at 0-15 and 15-30 cm depths combined, are presented in Table 11. There were significant differences in macro- and micronutrients extracted from the soils. Amounts

Table 11. Summary of mineral contents of nine Malaysian soils used for Hevea production, as extracted by three reagents.[†]

Extractant	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
	----- ppm -----								
DA	4.0b [†]	43a	51a	15a	0.8b	1.1b	6.2b	210b	697b
EDTA-TEA	2.8b	18c	--	6b	0.6c	0.8c	3.9c	81c	163c
5 <u>N</u> HCl	25.3a	26b	58a	15a	1.3a	1.8a	9.7a	1831a	1639a

[†]Each figure represents average values of 0-15 and 15-30 cm horizon of samples taken in the tree-row and inter-row of nine soil series.

[‡]Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

of P, Cu, Zn, Mn, Fe, and Al extracted by 5 N HCl reagent were significantly higher than those extracted by the other two reagents, DA and EDTA-TEA. The DA reagent was most effective in extracting K, and generally equal to 5 N HCl in extracting Ca and Mg, and intermediate for other elements. The chelate reagent EDTA-TEA (pH 7.3) extracted the least quantity of each element in these soils.

During the course of data analysis, an anomaly was discovered in the soil Ca and K values when extracted by 5 N HCl. This was indicated by a significantly lower K and about equal Ca values extracted by this reagent when compared with DA extractions. On further investigation, it was confirmed that Ca and K values were suppressed appreciably in the analytical procedure as the strength of the acid increased (Appendix Table 50). It was shown that Ca values in standard N HCl and 5 N HCl solutions were suppressed by 6 to 10% and 37 to 40%, respectively, as compared with Ca values in 0.1 N HCl and DA standard solutions. Values for K were suppressed by 10 to 12% and 28 to 30% in N HCl and 5 N HCl, respectively. All soil extracts by 5 N HCl were diluted to N HCl prior to determination of K by flame emission and Ca by atomic absorption spectrophotometry. Since the standards used were in DA or 0.1 N HCl, it is likely that K values reported for 5 N HCl extractant are 10 to 12% low, and similarly, Ca values are 6 to 10% lower than their true values. Thus the values reported for Ca and K extracted by 5 N HCl are artifacts and real values would indicate that 5 N HCl extracted more Ca and equal or more K than DA. No problem artifacts were found in the analyses for other elements.

The pH (7.3) of the EDTA-TEA extractant, which was high relative to the very acidic soils in this study caused a dispersal of the soil during the extraction process. It is assumed that the high pH resulted in Fe and Al precipitation as hydroxides which may have had the effect of removing other extractable ions from the system by occlusion. Lam and Gammon (1976) were successful in extracting a maximum quantity of micronutrients from soils of pH 5.7 by using EDTA-TEA buffered at pH 8.3. Shuman and Anderson (1974) found that DTPA at pH 7.3 gave the best measure of plant-available Mn when the soil pH ranged from 5.8 to 6.8; however, Mn extracted by water was most highly correlated with plant uptake on strongly acid soils (pH 4.8).

Other characteristics of these three extractants will have to be considered when interpreting elements removed from acid Malaysian soils. The reserve acidity in the DA reagent is low; hence, further drop in pH of the soil-extractant mixture will be low. This will favor Al over Fe extractions and possibly reprecipitation of FePO_4 in the extraction process. An extreme example of this may be seen in the small quantity of P removed from Melaka soil (Table 15) relative to P removed by the other extractants (Tables 16 and 17). The EDTA-TEA extractant tended to favor Fe extraction over Al despite the high pH because of the formation of the Fe-EDTA chelate. This would prevent FePO_4 precipitation and may, in fact, release some precipitated FePO_4 to the extracting solution. Thus it appeared that when Fe dominated the Fe-Al- PO_4 system more P is extracted by EDTA-TEA than by DA as observed for Melaka and Subang soils (Tables 15 and 16). The 5 N HCl contains so much reserve acidity that much more total Fe is extracted and the excess acidity prevents the

reprecipitation of Fe (Table 11). Interpretation of results obtained with these three extractants will have to be modified by a knowledge of the characteristics of the individual soils particularly as to the Fe and Al contents.

Mineral Contents as Related to Row and Depth

The mineral contents between tree-row and inter-row at the same depth were not significantly different (Tables 12 to 14). However, values for some mineral elements, particularly P, showed relatively higher average values in the tree-row of each depth as extracted by the different reagents. Although it is customary for most of the fertilizers (especially P) to be applied at the base of the tree (tree-row) during the early establishment stages, later applications may be made in the inter-row. Since these plantings were under somewhat different management systems the zone of maximum P accumulation changed from plantation to plantation (Appendix Table 39) and the average for all plantations was not significant.

Micronutrient contents such as Cu, Zn, Mn, and Fe did not appear to differ significantly between rows. However, it was noted that some elements, especially Zn and Mn, have a tendency to show a consistent and relatively higher value in the inter-row. Since leaf fall has been associated with the higher organic matter content in the inter-row, it is possible that this accumulation represented a form of nutrient recycling.

The overall differences in nutrient contents between the two depths, regardless of the row, were only significant for P and Ca (by DA and

Table 12. Differences in soil mineral contents extracted by DA at two sampling locations on nine Malaysian soils used for Hevea production.

Row	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
	<u>0-15 cm</u>								
Tree-row	8.6	51	63	15	0.8	1.0	7.1	189	708
Inter-row	2.8	47	61	18	0.8	1.3	7.6	214	714
Average	5.7a [†]	49a	62a	16a	0.8a	1.2a	7.3a	201a	711a
	<u>15-30 cm</u>								
Tree-row	2.6	41	42	11	0.7	1.0	4.9	231	704
Inter-row	1.8	34	40	15	0.7	1.1	5.3	219	690
Average	2.2b	37b	41b	13a	0.7a	1.0a	5.1a	225a	697a

[†]Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

Table 13. Differences in soil mineral contents extracted by EDTA-TEA (pH 7.3) at two sampling locations on nine Malaysian soils used for Hevea production.

Row	Mineral content						
	P	K	Mg	Cu	Zn	Mn	Fe
-----ppm-----							
				0-15 cm			
Tree-row	3.9	20	5	0.7	0.8	3.5	93
Inter-row	2.7	20	6	0.7	0.9	6.8	85
Average	3.3a [†]	20a	6a	0.7a	0.9a	5.2a	89a
				15-30 cm			
Tree-row	3.6	17	7	0.4	0.6	2.7	68
Inter-row	1.2	14	7	0.5	0.8	3.2	70
Average	2.4a	16a	7a	0.5a	0.7a	3.0a	69a

[†]Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

Table 14. Differences in soil mineral contents extracted by 5 N HCl at two sampling locations on nine Malaysian soils used for Hevea production.

Row	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
0-15 cm									
Tree-row	45.4	29	70	12	1.5	1.7	10.6	1826	1559
Inter-row	22.4	29	81	22	1.4	2.0	12.0	1874	1696
Average	33.9a [†]	29a	76a	17a	1.5a	1.9a	11.3a	1850a	1628a
15-30 cm									
Tree-row	18.9	22	43	14	1.1	1.6	7.6	1780	1638
Inter-row	14.2	22	44	16	1.1	1.8	8.5	1845	1663
Average	16.6b	22a	44b	15a	1.1a	1.7a	8.1a	1813a	1651a

[†]Means within column followed by same letter are not significantly different at 0.05 level by DMRT.

5 N HCl extraction), and for K by the DA extraction. The greater concentration of P and Ca in the surface 0-15 cm soils may be related to the build-up of these elements from rock P or other forms of P fertilizers that were previously applied. Owen (1947) found that in most Malaysian soils, a greater portion of the applied P was retained within 7.5 cm of the surface. The Rubber Research Institute of Malaysia (1974) reported increases in Ca and P in soils that had been fertilized with rock P.

Among the micronutrients and Al (except B), the overall average values between the two depths, regardless of the row, were not significantly different even though values in the surface 0-15 cm tended to be slightly higher. Practically no micronutrient fertilizers were applied to the Hevea plantations, except for the inadvertent applications of trace elements as contaminants in rock P and other fertilizers. Hence, it may be assumed that most of the micronutrients extracted represent natural soil reserves. The slight but constantly higher levels found in the soil surface suggest the possibility of the addition of some elements through fertilizer contaminants and nutrient cycling of leaf fall. The downward movement of most micronutrients can be considered as negligible for most soils (Hodgson, 1963). Hot water-soluble B (Table 18) was found to be significantly higher in the 0-15 cm than the 15-30 cm horizon. Although B is generally considered to be water-soluble and easily leached, the presence of amorphous materials, especially Fe and Al hydroxides, is active in B retention (Sims and Bingham, 1968b).

Average Mineral Content of Different Soils

The average mineral contents of twelve soil samples taken from the tree-row and inter-row areas at 0-15 and 15-30 cm depths are shown in Tables 15 to 17, representing DA, EDTA-TEA, and 5 N HCl extractions, respectively. All three methods of extraction showed significant variations in extractable mineral contents among soil series. Although there were differences in the quantities extracted by each reagent, the relative differences in extractable minerals among soil series remained rather consistent. Exceptions noted for Fe, Al, and P may be attributed to chemical characteristics of the soils and extracting solutions as previously discussed.

Soils from Subang and Selangor series were higher in mineral contents than the other soils, thus reflecting their higher content of less weathered clays. The larger quantities of extractable P found in Selangor, Subang, and Melaka series (Table 17), may be associated with their higher Ca, Fe, and/or Al contents. The large increase in P extracted by 5 N HCl would tend to confirm that much of the P was in Al and Fe compounds.

Extractable K by all methods of extraction were significantly different among soil series. With the exception of Subang series (with 137 ppm K) most of the soils were generally low in K which ranged from 25 to 67 ppm in Melaka and Selangor series, respectively. Since the clay mineralogy data on Subang soils are not available to explain the high K found in this soil, it can be assumed that the high organic matter content played a key role in slowing the leaching of K fertilizers. Selangor and Durian soils were expected to contain significantly higher quantities

Table 15. Summary of mineral contents extracted by DA from nine Malaysian soils used for Hevea production.[†]

Soil series	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
	-----ppm-----								
Durian	5.0a [‡]	58b	36de	11cd	0.4b	0.8a	2.2d	355a	740c
Serdang	4.0a	39c	88c	14c	0.9a	2.3a	26.5a	193abc	343e
Munchong	2.4a	32cd	23e	7d	1.4a	1.2a	2.3d	263ab	551cde
Malaka	0.4a	25d	35de	7d	1.2a	0.8a	3.3d	228abc	397de
Subang	3.6a	137a	125b	24b	0.2b	1.4a	3.6d	145abc	2063a
Hollyrood	6.4a	32cd	35de	7d	0.4b	0.8a	7.6c	143bc	506cde
Selangor	6.7a	67b	205a	105a	0.2b	1.3a	17.7b	50c	1383b
Harimau	1.6a	38c	35de	9cd	0.9a	1.5a	1.4d	305ab	736c
Rengam	4.7a	38c	48d	8cd	0.3b	0.7a	3.3d	202abc	710cd

[†]Each figure represents average values of 0-15 and 15-30 cm horizon of samples taken in the tree-row and inter-row.

[‡]Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

Table 16. Summary of mineral contents extracted by EDTA-TEA (pH 7.3) from nine Malaysian soils used for Hevea production.[†]

Soil series	Mineral content						
	P	K	Mg	Cu	Zn	Mn	Fe
							Al
Durian	3.0ab [‡]	14cd	3b	0.3bc	0.7a	1.3c	128b
Serdang	1.1b	13cd	4b	0.5abc	1.7a	20.0a	64b
Munchong	2.0b	9d	3b	0.9a	0.7a	1.4c	71b
Melaka	3.2ab	5d	3b	0.9a	0.6a	2.8c	71b
Subang	14.5a	60a	6b	0.7abc	1.1a	2.0c	355a
Holyrood	1.6b	20c	3b	0.2c	0.7a	5.6b	34b
Selangor	4.1ab	33b	56a	0.4abc	0.8a	6.3b	79b
Harinau	0.7b	21c	3b	0.5abc	0.7a	0.8c	40b
Rengam	2.5ab	15cd	3b	0.2c	0.4a	1.3c	67b
							65b

[†] Each figure represents average values of 0-15 and 15-30 cm horizon of samples taken in the tree-row and inter-row.

[‡] Means within column followed by same letter are not significantly different at 0.05 level by DMRT.

Table 17. Summary of mineral contents extracted by 5 N HCl from nine Malaysian soils used for Hevea production.[†]

Soil series	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
Durian	14.0d [†]	29c	31ef	11c	0.7bc	1.3a	4.0e	3113b	1352d
Serdang	13.0d	34bc	68c	8cd	1.1b	2.8a	34.0a	1182g	385e
Munchong	30.0c	18d	27f	7cd	2.0a	1.6a	4.0e	1848d	1282d
Meiaka	40.0b	13d	48cde	9cd	2.2a	1.3a	8.4d	2009c	1047d
Subang	68.4a	65a	119b	25b	2.2a	2.5a	6.7d	6107a	5350a
Holyrood	14.5d	21d	53cd	4d	0.4c	1.8a	13.0c	667h	1287d
Selangor	32.0bc	43b	239a	120a	1.8a	3.0a	24.0b	1677e	3615b
Harimau	12.8d	39bc	35ef	8cd	1.1b	2.1a	2.0e	1479f	1186d
Rengam	17.3d	14d	43def	9cd	0.5bc	1.1a	4.0e	1827de	1733c

[†]Each figure represents average values of 0-15 and 15-30 cm horizon of samples taken in the tree-row and inter-row.

[‡]Means within column followed by same letter are not significantly different at 0.05 level by DMRT.

of K (Table 14), since they are known to contain some illite and mica in their clay minerals; in the absence of these minerals, soils such as Melaka series are very low in K content.

Based on available records of annual fertilizer application, it appears that much of the applied K could not be accounted for in the soil extractions. Evidently the K fertilizers applied are either readily leached from the soil or easily taken up by the Hevea trees. Leaf analysis of Hevea grown on these soils (as discussed later) indicate an adequate to high range of K content.

Soil Ca and Mg extracted by DA showed significant variations among soil series. The quantities of Ca and Mg extracted by 5 N HCl and the DA methods were in close agreement. The soils were generally low in Ca and Mg with the exceptions of Selangor and Subang series. The quantities of these cations seemed to be directly related to the soil clay minerals.

The Cu, Mn, Fe, and Al contents varied significantly among soil series (Tables 15 to 17). The high variability of Zn within soil series prevented significant differences among soil series, although some of these differences were relatively large. Extractable Cu, Zn, and Mn averaged in the low to adequate range but some were deficient by temperate zone soil standards (Cox and Kamprath, 1972). The significantly low amounts of extractable Cu in Subang, Selangor, and Rengam soils may be related to the high organic matter content of these soils. Bolle-Jones (1957a) reported that Cu deficiency frequently occurs in soils rich in organic matter, particularly peat soils, found in the coastal areas; whereas soils derived from sandstone parent material generally have a higher micronutrient content, especially of Mn. Other soils that

Table 18. Boron content of nine Malaysian soils used for Hevea production at selected sampling sites.

Soil series	Row		Horizon	
	Tree-row	Inter-row	0-15 cm	15-30 cm
-----ppm-----				
Durian	0.25a [†]	0.32a	0.37bc	0.20c
Serdang	0.28a	0.37a	0.33c	0.32abc
Munchong	0.24a	0.35a	0.35c	0.25bc
Melaka	0.27a	0.43a	0.30c	0.40abc
Subang	0.52a	0.47a	0.57ab	0.42ab
Holyrood	0.28a	0.28a	0.33c	0.23bc
Selangor	0.45a	0.43a	0.45abc	0.43a
Harimau	0.52a	0.37a	0.65a	0.23bc
Rengam	0.30a	0.28a	0.35c	0.23bc
Average	0.31m [‡]	0.35m	0.38x [§]	0.28y

[†] Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

^{‡§} Means between rows or between horizons followed by same letter are not significantly different at 0.05 level by DNMR.

originated from argillaceous shales (such as Durian, Melaka, and Munchong), organic enriched alluvial deposits (Subang), and granite (Rengam) generally had low micronutrient reserves. Quantities of Fe and Al extracted varied significantly among soil series. The levels were generally high and 5 N HCl extracted the largest amounts. Neither Al nor Fe quantities followed a pattern that was known to be related to Hevea yields. However, high Al and Fe values were associated with the higher levels of 1:1 minerals and amorphous clay materials.

Levels of hot water extractable B were in the low to adequate range (Table 18). Soils developed from marine alluvium (Subang, Selangor, and Harimau) had distinctly higher B supplies. Shorrocks (1964) reported that soils derived from acid granite and coastal deposits were expected to contain higher concentrations of B. This emphasizes the importance of geochemical aspects of soil formation in determining the micronutrient reserves in these soils.

Distribution of Minerals Within Soil Profiles

Mineral nutrients and Al were extracted with three extractants, DA, 5 N HCl, and EDTA-TEA (pH 7.3), from samples taken at different horizons of soil profiles. These horizons were differentiated on the basis of color or visual textural changes. Data are presented in Tables 19 to 21. Results obtained may be most appropriately discussed with reference to the parent materials and clay mineralogy of these soil series (Noordin, 1977).

Table 19. Selected chemical properties and distribution of minerals, as extracted by DA, in nine Malaysian soils used for Hevea production.

Depth	pH		Organic matter	Mineral content									
	H ₂ O	N KCl		P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al	
	-----ppm-----												
cm	% -----												
				<u>Durian</u>									
0-15	4.16	3.39	2.54	17.8	64	268	43	0.2	0.9	9.0	173	470	
15-43	4.23	3.33	1.05	0.8	57	59	19	0.2	0.6	1.9	208	515	
43-71	4.02	3.25	0.66	0.3	59	37	12	7.4	2.3	0.8	92	634	
71-97	4.12	3.30	0.54	tr	63	36	13	0.3	1.5	0.7	48	728	
97-152	4.30	3.27	0.33	tr	102	45	19	0.3	1.1	0.7	39	812	
				<u>Serdang</u>									
0-5	4.38	3.49	1.17	2.4	60	32	6	0.6	0.6	10.2	143	244	
5-30	4.53	3.59	0.79	0.6	66	27	4	0.5	0.6	4.1	189	336	
30-61	4.43	3.53	0.33	0	46	24	4	0.5	0.6	1.7	140	352	
61-130	4.37	3.44	0.47	0	50	22	6	0.6	0.8	0.8	168	380	
130-150	4.41	3.48	0.27	0	8	16	2	0.4	0.4	0.8	76	400	

Table 19. (Continued)

Depth	pH		Organic matter	Mineral content								
	H ₂ O	N KCl		P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
cm	-----ppm-----											
	%											
	<u>Munchong</u>											
0-5	4.37	3.60	2.43	13.3	43	28	21	0.8	0.8	4.0	181	497
5-18	4.56	3.75	1.39	0.9	33	77	19	0.7	0.8	1.4	218	526
18-79	4.69	3.76	0.74	0.8	46	48	25	0.8	2.2	0.8	121	810
79-89	4.53	3.60	0.87	0.4	70	54	14	1.4	1.7	1.1	107	1105
89-147	4.31	3.24	0.14	0.9	16	20	3	0.8	1.0	0.8	64	640
	<u>Melaka</u>											
0-15	4.28	3.52	3.11	0.8	51	79	20	1.2	1.2	14.5	124	587
15-56	4.47	3.59	1.48	0.4	45	25	8	1.1	0.8	4.0	113	640
56-81	4.55	3.68	0.91	0.3	53	28	6	0.7	1.0	2.1	44	560
81-127	4.31	3.44	0.49	0.5	48	24	7	1.2	0.7	0.4	30	420

Table 20. Distribution of minerals, as extracted by EDTA-TEA (pH 7.3), in nine Malaysian soils used for Hevea production.

Depth	Mineral content							
	P	K	Mg	Cu	Zn	Mn	Fe	Al
cm	-----ppm-----							
Durian								
0-15	6.6	42	46	0.7	0.9	8.6	273	428
15-43	1.8	28	21	0.5	0.6	1.4	138	460
43-71	1.7	20	14	3.5	1.5	0.5	60	649
71-97	3.3	16	11	1.0	1.5	0.7	28	802
97-152	0	33	17	0.5	0.7	0.6	19	939
Serdang								
0-5	3.0	74	10	1.0	0.6	10.7	170	276
5-30	1.0	89	8	0.6	2.4	3.0	148	268
30-61	0.2	60	8	0.6	2.8	1.4	95	280
61-130	0.5	26	7	0.5	0.7	1.0	56	276
130-150	0.2	5	4	0.2	0.4	0.4	32	344
Munchong								
0-5	2.8	44	17	1.2	5.3	3.1	308	526
5-18	0.2	26	24	0.7	6.8	1.3	149	426
18-79	1.3	23	25	0.6	3.6	0.6	73	356
79-89	0.6	25	14	1.2	3.4	0.7	52	676
89-147	0.6	4	4	0.8	0.9	0.4	32	720

Table 20. (Continued)

Depth	Mineral content							
	P	K	Mg	Cu	Zn	Mn	Fe	Al
cm	-----ppm-----							
	<u>Melaka</u>							
0-15	1.1	33	20	0.5	1.3	11.7	135	32
15-56	0.5	17	7	0.5	0.6	1.8	86	350
56-81	2.4	18	5	0.6	0.6	0.9	24	280
81-127	0.1	14	5	0.7	0.8	0.4	20	428
	<u>Subang</u>							
0-20	5.0	49	11	0.7	1.5	2.5	301	1133
20-53	4.5	87	5	0.6	1.2	5.3	290	1260
53-91	0.5	11	3	0.2	0.2	0	4	76
91-127	0.3	16	5	0.2	0.4	0	4	24
	<u>Holyrood</u>							
0-18	0.7	74	19	0.4	0.9	8.1	160	538
18-56	0.2	46	12	0.3	0.6	3.8	144	494
56-117	0.4	32	14	0.2	0.6	6.5	52	245
117-147	0	38	67	0.4	1.4	24.5	27	174

Table 20. (Continued)

Depth cm	Mineral content							
	P	K	Mg	Cu	Zn	Mn	Fe	Al
	-----ppm-----							
	<u>Selangor</u>							
0-5	13.5	81	18	1.7	4.1	9.6	560	1880
5-28	0.8	55	10	1.1	2.9	2.7	290	1843
28-66	1.3	76	85	1.4	3.1	20.7	1127	1576
66-86	2.4	52	11	0.6	3.4	0.4	1277	844
86-102	0	50	20	1.8	5.0	3.2	1148	2360
	<u>Harimau</u>							
0-17	0.1	91	18	0.6	2.0	1.5	293	684
17-43	0.2	59	10	0.5	1.9	0.7	141	395
43-78	0.1	50	10	0.4	0.5	0.5	59	327
78-135	0.1	46	9	0.5	0.6	0.4	25	290
	<u>Rengam</u>							
0-8	0.9	50	22	0.8	1.1	4.8	230	722
8-23	0.2	21	10	0.5	0.7	1.2	119	385
23-61	1.0	14	9	0.7	0.7	0.8	80	356
61-109	3.3	49	14	2.1	1.3	1.3	90	542
109-132	2.5	43	21	1.0	0.9	1.2	51	533

Table 21. Distribution of minerals, as extracted by 5 N HCl, in nine Malaysian soils used for Hevea production.

Depth	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
cm	-----ppm-----								
	<u>Durian</u>								
0-15	23.4	56	291	39	0.7	1.2	14.0	1693	1068
15-43	1.8	39	59	14	0.2	0.8	4.0	1929	1112
43-71	2.7	38	33	8	0.3	1.3	2.9	2051	1394
71-97	0.4	34	29	7	1.0	0.9	2.5	2323	1511
97-152	0.3	45	29	9	0.2	0.4	1.4	1683	1507
	<u>Serdang</u>								
0-5	6.2	45	32	6	1.2	1.0	25.2	953	372
5-30	1.6	46	30	4	0.7	0.8	12.9	1303	650
30-61	2.1	35	26	4	0.7	1.2	11.3	1250	776
61-130	0.4	49	20	4	1.2	0.8	9.6	2600	1160
130-150	1.0	9	16	3	0	0.6	2.4	1456	1200
	<u>Munchong</u>								
0-5	5.3	31	27	10	0.9	1.2	6.3	1354	1000
5-18	1.3	25	73	17	0.3	0.8	4.0	1729	1396
18-79	0.2	30	35	16	0.6	0.9	3.1	1370	1364
79-89	4.5	24	30	8	1.3	1.6	4.2	3697	1940
89-147	0	17	16	2	0.8	1.0	2.4	3200	1920

Table 21. (Continued)

Depth	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
cm	-----ppm-----								
	<u>Melaka</u>								
0-15	5.7	42	83	18	2.4	1.7	22.9	2163	2240
15-56	1.5	43	24	6	2.1	1.3	17.6	3027	2987
56-81	0.6	50	24	5	2.1	1.3	10.1	2627	2853
81-127	0	48	28	5	2.0	0.9	8.4	3220	1600
	<u>Subang</u>								
0-20	41.2	130	144	16	2.9	3.4	11.2	6867	1688
20-53	15.9	154	59	20	2.4	2.9	5.1	3947	1523
53-91	9.4	188	101	15	1.0	2.6	1.7	869	869
91-127	6.7	167	408	269	0.9	11.9	3.6	760	592
	<u>Holyrood</u>								
0-18	8.4	31	59	9	0.3	0.1	21.5	623	1029
18-56	4.4	23	28	5	0.2	0.2	9.2	943	2101
56-117	4.6	15	42	6	0.1	0.1	13.5	646	2023
117-147	1.5	20	150	34	0.3	1.2	10.8	511	1276

Table 21. (Continued)

Depth	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
cm	-----ppm-----								
	<u>Selangor</u>								
0-5	31.2	49	126	35	2.6	3.1	6.8	1317	2458
5-28	4.6	50	23	18	1.0	3.2	3.1	1061	2271
28-66	28.0	72	41	267	2.2	1.6	10.1	3135	2082
66-86	20.2	85	17	30	1.8	2.5	3.4	4299	1532
86-102	8.8	122	40	68	5.6	6.6	11.2	7040	3520
	<u>Harimau</u>								
0-17	15.2	25	26	8	0.5	1.3	3.0	1256	1394
17-43	1.6	14	15	4	2.0	1.1	1.7	1287	1370
43-78	0.5	13	17	3	0.2	0.6	1.5	1036	1294
78-135	0.2	12	39	3	0.2	0.6	1.4	900	1398
	<u>Rengam</u>								
0-8	27.8	43	77	15	1.5	3.3	7.6	1817	2239
8-23	1.7	15	17	5	0.5	0.8	3.2	1830	1551
23-61	0.8	10	12	3	0.6	1.3	5.0	1606	1429
61-109	0.5	9	11	4	0.4	0.8	1.6	1242	1217
109-132	0.5	13	13	3	0.5	2.0	1.3	963	1173

Phosphorus

Downward movement of P in these acid soils which are high in Fe and Al is practically nil. Most fertilizer P is applied to the soil surface except for some young trees or for older plantings on steep slopes where P could be lost in surface runoff, the P fertilizers may be "pocketed," i.e., applied a few centimeters below the surface. Since soil cultivation is not a usual practice, P may be expected to remain essentially at the point of application. This is generally confirmed by the data obtained. Actual concentration found in the surface horizons may be largely artifacts of sampling depth (dilution) rather than representing the P concentration throughout the horizon. Generally P was higher in the surface horizon and decreased with depths reflecting the common fertilizer practices.

While the "available" P as measured by DA extractant was very low for all soils (Table 19), there seemed to be some reserve P in the 28-66 and 66-86 cm horizons of the Selangor and the 20-53 cm horizon of the Subang series as extracted by EDTA-TEA and 5 N HCl (Tables 20 and 21). Since both of these extractants also removed rather large quantities of Fe and Al from these horizons, it is assumed that this P was present in the Fe and Al forms which had limited availability to plants. High P in the second horizon of the Subang series may be related to the movement of surface applied P as organic complexes since this soil was high in organic matter content. Soils of the Selangor series contained significant quantities of 2:1 clay minerals and presumably P in the lower horizons of the soils was from P-bearing minerals that were present during soil development.

Potassium

Extractable K generally decreased slightly but irregularly with depth. Concentrations declined abruptly at lower depths (Table 19) for some series reflecting K mobility within the soil profile. Soil profiles from Durian and Selangor series exhibited an appreciable increase in K at the lowest depth. The generally high K concentrations of these two soils may be attributed to the presence of illite and mica. Highest levels of extractable K were found in the Subang soils. Since organic matter is not very retentive of K at such low pH levels, it is likely that the alluvium deposited in these soils also contains illite, mica, or other 2:1 clay minerals.

Calcium

With exception of Subang, Harimau, and Holyrood series, the soil profiles exhibited a general decrease in extractable Ca with depth (Table 19). Higher Ca concentrations at the 117 to 147 cm depth of Holyrood soils and the increasing pattern of Ca concentration with depth in the Harimau series were readily reflected in their pH values and may be associated with calcareous materials at greater depths. The Ca concentrations in the surface layers of Durian, Melaka, Selangor, and Rengam soils were about three to six times greater than at the lower depths. High Ca levels in the surface reflect regular applications of rock phosphate in the fertilizer program. Additional Ca may be supplied when dolomite is used as a Mg source. Distribution of Ca in these soils may be related to time of application as well as to organic matter and

content of clay materials. The Subang soils contained highest levels of exchangeable Ca, and Ca increased with depth from the second to the fourth horizon following a pattern similar to that of organic matter content.

Magnesium

With exception of the Subang and Selangor series, extractable Mg generally decreased with depth in the soil profile (Tables 19 and 20). An increase in Mg content with depth was noted for Subang and Selangor soils which may be associated with the organic matter content and 2:1 clay minerals, respectively. A low reserve of extractable Mg was found in soils of Serdang, Melaka, Holyrood, Harimau, and Rengam series (Table 21). These soils were dominated with 1:1 clay minerals indicating that they have proceeded to an advanced stage of weathering and a consequent loss of Mg-bearing minerals. Extractable Mg tends to be uniformly distributed throughout the profile in most of these soils suggesting a constant downward leaching of this element and return by plant cycling.

Copper

Extractable Cu generally averaged less than 1 ppm in most of the soil profiles investigated (Tables 19 to 21). The acid extractants, especially 5 N HCl, generally extracted more Cu than EDTA-TEA except for the Holyrood series. Acid extractable Cu averaged a little higher in the Melaka, Subang, and Selangor series. For temperate zone soils an acid extractable Cu level of 0.5 to 1.0 ppm is usually adequate for normal growth (Fiskell and Leonard, 1967). There was a general tendency for

extractable Cu to be uniformly distributed throughout the soil profile. In this investigation, Selangor series was the only soil that showed an appreciable increase in extractable Cu at the lower depth. This observation could be attributed to the geochemical nature of this soil which was derived from marine alluvium. The increase in extractable Cu concentration at the 43-71 cm depth of Durian soils was associated with an increase in extractable Zn. Since there was a drop in pH in this horizon, it is probable that Cu and Zn bearing minerals in the form of sulfides occurred at that particular depth.

Zinc

Extractable Zn in most of the soil profiles was slightly higher than Cu. There appears to be no consistent pattern in the distribution of extractable Zn within the soil profiles (Tables 19 to 21). The variation in concentration of extractable Zn with depth seemed to be related to soil texture and the occurrence of Zn-bearing minerals such as observed in Durian, Holyrood, and Selangor soils. On the whole, extractable Zn was low, averaging less than 3 ppm in most of the soil profiles and in Serdang and Harimau profiles the DA-extractable Zn averaged less than 1 ppm (Table 19). An acid extractable Zn level of 1 ppm or less is generally considered critical for Temperate Zone soils (Martens et al., 1966). Soils that were derived from marine alluvium (Selangor) and organic enriched alluvial deposits (Subang) seemed to contain relatively higher levels of extractable Zn throughout the soil profile.

Manganese

Distribution of extractable Mn in most of the soil profiles shows a consistent decreasing concentration pattern with depth (Tables 19 to 21). However, Mn extracted by 5 N HCl in Selangor and Holyrood series increases in a variable manner at the lower depths (Table 21). The accumulation of Mn in the surface horizons of well-drained soils may be associated with the organic matter content and nutrient recycling. However, for poorly-drained Spodosols, Gammon and Hai (1978) demonstrated that Mn accumulation in the surface layer was the result of upward movement of Mn^{2+} during periods when the soil was saturated. At the soil surface, the Mn^{2+} was oxidized to less soluble forms which were not leached by rainfall. This process would likely occur on poorly drained soils in Malaysia.

Extractable Mn was much higher in the surface horizon than the horizon below. With a few exceptions noted, further decrease in Mn with depth was gradual. Soils derived from sandstones (Serdang), argillaceous shales (Melaka), riverine alluvium (Holyrood), and marine alluvium (Selangor) contained higher concentrations of extractable Mn in lower horizons (Table 20). On the other hand, soils that were derived from older alluvium (Harimau) and granite (Rengam) are relatively low in extractable Mn. An occasional increase in concentrations of extractable Mn occurred at lower depths of some profiles which indicates old surfaces or points of deposition related to favorable oxidation, as shown in Holyrood and Selangor soils. Temperate Zone soils with an acid extractable Mn level of 5 ppm or less may be deficient for some crops. Slightly lower levels may be acceptable on very acid soils. Only the Harimau series in this study appeared likely to be Mn deficient.

Iron and Aluminum

Extractable Fe and Al were generally high in all the soils investigated (Tables 19 to 21). High Fe and Al contents have been considered to be a distinguishing characteristic of highly weathered tropical soils. There were two distinct patterns in the distribution of extractable Fe in the soil profile. The first was a decrease in extractable Fe concentration with depth as shown in Durian, Melaka, Holyrood, and Harimau profiles (Table 19). The second pattern was a gradual increase in Fe concentration in the horizons immediately below the surface followed by little change with further increases in depth as indicated in Serdang, Munchong, and Selangor series. More Fe was extracted by 5 N HCl than by other extractants (Table 21) and the distribution pattern was somewhat altered. With the exception of Selangor and Subang soils, the high extractable Fe values may be attributed to goethite contents. Although goethite is reportedly absent in Selangor soils, the high extractable Fe concentration observed at the lower depth of this profile may be attributed to FeS in this sulfide-rich horizon as indicated by the drop in pH.

Extractable Al increased with depth in Durian, Serdang, and Munchong soil; whereas, a decrease was observed in Holyrood, Harimau, and Rengam soils (Table 19). High extractable Al values throughout the soil profile were noted in Melaka and Selangor series. Higher Al concentrations at lower depths of some soil profiles probably indicate that translocation of this element downward from the surface horizons had taken place due to the intensive weathering and leaching. The presence of gibbsite in certain soils, such as Melaka and Munchong, was reflected in the extractable Al content. Hevea is obviously tolerant of high Al levels in

the soil. No information is available on possible effects of Al on uptake of micronutrients. However, the effects of high Fe or Al on P availability are well documented (Taylor and Gurney, 1965; MacLean and Chiasson, 1966).

Effect of Clones and Soils on Mineral Contents of Hevea Leaves

Interclonal Variation

The interclonal variation in mineral nutrient contents of leaves and average annual latex yields were examined for four Hevea clones, RRIM 600, RRIM 605, PB 5/51, and GT 1. Each clone was grown on two contrasting soils, Munchong and Holyrood. These soils were ranked as class Ia and III, respectively, in terms of their suitability for Hevea production (Table 3). Since critical mineral concentrations in Hevea bark and bark-scrap rubber have not been determined, only leaf tissue values are reported in this study. The critical values for many nutrient elements in Hevea leaves had been formulated (Table 22), and will be frequently cited in the following discussion.

Based on the available 1977 average production records on Munchong and Holyrood soils, Hevea clone RRIM 600 produced the highest yield and clone RRIM 605 the lowest among the four clones (Table 23). The other two clones, PB 5/51 and GT 1, are similar but intermediate in yield.

Significant differences in mineral concentrations in Hevea leaves were found among the clones, except for Cu and Zn. The concentrations of P in the leaves for all clones were generally in the low to deficient range. In clone RRIM 605, the exceptionally low P concentrations found

Table 22. Range of mineral nutrient concentrations in Hevea leaves at optimum age taken from an area shaded by the canopy (Pushparajah and Tan, 1972).

Nutrient	Group [†]	Low [‡]	Medium	High	Very high
-----%-----					
P		< 0.19	0.20-0.25	0.26-0.27	> 0.28
K	I	< 1.25	0.26-1.50	1.51-1.65	> 1.66
	II	< 1.35	1.36-1.65	1.66-1.85	> 1.86
Mg		< 0.20	0.21-0.25	0.26-0.29	> 0.30
-----ppm-----					
Mn		< 45	45-150	> 151	

[†]Group I--All other clones that are not in Group II (normal K requirement).

Group II--Clones RRIM 600, PB 86, PB 5/51, GT I (high K requirement).

[‡]Low--Indicates that the mineral level is well below suboptimal level
Medium--Indicates suboptimal level.

High--Indicates level above which improved growth or yield responses are unlikely.

Very high--Indicates excess level.

Table 23. Average mineral contents of leaves and 1977 average latex yields of four Hevea clones grown on Munchong and Hollyrood soils.

Clones	Mineral content								Latex yield		
	P	K	Ca	Mg	Cu	Zn	Mn	Fe		B	Al
-----%-----ppm-----											
RRIM 600	0.17b [†]	1.67c	0.75b	0.22b	9a	23a	56b	30b	12a	21b	1795
RRIM 605	0.14c	1.80b	1.06a	0.19c	9a	26a	150a	7c	10b	12b	1359 [‡]
PB 5/51	0.15c	1.95a	0.44c	0.15d	9a	23a	52b	34b	14a	44a	1518
GT 1	0.18a	1.83ab	0.83b	0.25a	8a	28a	137a	44a	9b	38a	1582 [‡]

[†]Means within column followed by same letter are not significantly different at 0.05 level by DNMR.

[‡]Yields on Munchong soil only.

in the leaves were associated with high Ca concentrations, while low P in clone PB 5/51 was associated with low Ca and very low Mg content.

The K concentrations in the leaves for all clones were found in the high to excess range. Clone RRIM 600, a member of Group II which has a high K requirement, contained less K in the leaves than RRIM 605 which has a lower requirement; however, all K levels are above the optimum range.

Leaf Mg was significantly below the optimum level for clone RRIM 605 and possibly deficient for clone PB 5/51. The low Mg concentrations for clone PB 5/51 appear to be associated with the high K and low Ca concentrations in the leaves. For diagnostic purposes when examining leaves suspected of being incipiently deficient in Mg, Bolle-Jones (1954b) advocated the use of comparison of K/Mg ratio values with healthy laminae rather than to depend solely on the concentration of Mg as the decisive criterion. Bolle-Jones and Ratnasingam (1954) studied interclonal variation in three Hevea clones and reported that the highest K/Mg ratio and the lowest Mg concentration found in the laminae of clone PB 86 was associated with the susceptibility of this clone to Mg deficiency. From all evidence, clone PB 5/51 in this study seemed to have the lowest Mg concentration and the highest K/Mg ratio in the leaves when compared with the other clones. The general description given by Bolle-Jones and Ratnasingam (1954) regarding Mg status thus fits well for clone PB 5/51 which suggested possible susceptibility of this clone to Mg deficiency.

Calcium has been correlated indirectly with rubber production; however, Hevea is reported to have a low Ca requirement (Bolle-Jones, 1954a). Guha and Narayanan (1969) stated that Ca status of Hevea was generally considered to be adequate in peninsular Malaysia; however, the

sufficiency level of Ca in Hevea has not been precisely determined. Previous studies indicated that Ca concentrations in Hevea leaves generally ranged from 0.50 to 0.90% (Pushparajah, 1969; and Bolle-Jones, 1954a). In this study, only clone PB 5/51 had a Ca concentration in leaves lower than this range. Since sampling of leaves was carried out at a time when the fluctuation in mineral contents was minimum, it seems probable that clone PB 5/51 has a lower Ca requirement and is not necessarily deficient. Leaf Ca concentration in clone RRM 605 was exceptionally high and seemed to be related to the low Mg content. Barber (1964) reported that high Ca/Mg ratios could affect crop yield when the soil exchangeable Mg falls below 50 ppm. The high Ca content in rock phosphate, a common source of P for Hevea, is known to depress latex flow (Pushparajah, 1966). This is a possible evidence that the low yield obtained for clone RRM 605 was related to the high Ca/Mg ratio.

Among the micronutrients, only Cu and Zn concentrations in the leaves did not differ significantly among the four Hevea clones. The critical levels of Cu and Zn in Hevea leaves have not been established. According to Bolle-Jones (1957a), Cu deficient laminae of Hevea seedlings contained 2 to 3 ppm of Cu while the Cu concentration in the healthy leaves was about 10 ppm. Based on these findings, the Cu level for all clones appeared to fall within the low to adequate range.

Under controlled experiments, Bolle-Jones (1957b) observed Zn deficiency symptoms in laminae of Hevea seedlings when the concentrations were about 12 to 15 ppm and healthy laminae contained 16 to 21 ppm or more Zn. The Zn concentrations found in the leaves for all clones in this study were well within the optimum range.

According to the established critical levels, Mn concentrations in the leaves of all Hevea clones studied fall within the adequate range. However, Mn concentrations were found to be significantly higher in clones RRIM 605 and GT 1 than clones RRIM 600 and PB 5/51.

The critical level for Fe in Hevea leaves has not been determined. Bolle-Jones and Ratnasingam (1954) studied the interclonal variation of three Hevea clones, Tjir 1, PB 86, and RRIM 501, and found the average Fe concentrations in the leaves ranged from 68 to 75 ppm. He also reported that Fe concentrations increased in the leaves with increased rainfall, which enhanced the availability of Fe in the soil. The Fe concentrations in the leaves for all clones in this study appeared to be very low and possibly deficient for clone RRIM 605. The low Fe concentration observed in the leaves of clone RRIM 605 was probably related to the high Mn concentration. Chlorotic plants have been observed in acidic soils that also contained large amounts of available Mn (Somers and Shive, 1942). Epstein and Stout (1951) suggested that Mn interfered with the transport of Fe from the roots to the shoots. Of all of the mineral differences among clones observed (Table 23), the wide difference between Mn and Fe in clone RRIM 605 was likely to indicate a possible nutritional problem and may be associated with the lower yield of this clone, although the Ca/Mg ratio discussed earlier may also be a factor.

Concentrations of Al in the leaves for Hevea clones PB 5/51 and GT 1 were significantly higher than clones RRIM 600 and RRIM 605. The importance of Al in Hevea is not known. However, the relatively low Al uptake by all Hevea clones demonstrated that the adaptability of Hevea to acid soils includes the ability to reduce Al uptake.

The sufficiency range for B concentrations in Hevea leaves has not been formulated. Bolle-Jones (1954a) found that laminae taken from B deficient Hevea seedlings contained 9 to 10 ppm of B whereas complete nutrient plants contained as high as 215 ppm. He concluded that the B requirement for Hevea was low but this plant had the ability to tolerate high B concentration. Later, Shorrocks (1964) reported B toxicity symptoms in Hevea seedling leaves containing 140 to 150 ppm B. Based on these reports it seems that B concentration in the leaves for these clones fall in the deficient to low range. However, data should be carefully examined when attempting to interpret B status based on comparison to previous reports because in some instances it has not been possible to avoid contamination of samples or reagents during analytical procedures, since B-containing glassware was used. It is also known that different analytical methods can result in significant variation in B values obtained. The lack of consistent B data obtained in previous studies with Hevea may well be associated with analytical methods.

Effect of Soil Variation

The main objective of this investigation was to examine differences in yield and leaf mineral contents of Hevea clone RRIM 600 when grown on nine different soil series representing different locations in Malaysia. The clone chosen, RRIM 600, is a high latex producer that is widely grown in peninsular Malaya. Information is needed to determine if yield variations for this Hevea clone are associated with differences in mineral concentrations observed in the leaves and whether such differences may be correlated with soil characteristics, particularly extractable mineral contents.

Suitability class rankings of the nine soils as proposed by Chan and Pushparajah (1972) are listed in Table 24 together with the average production on the soils used in this study for 1977. The proposed general class ranking of these soils does not agree very well with the observed 1977 latex production data. Although their class rankings were low, Hevea yield performance on Durian and Serdang soils was better than those of other soils, especially the Harimau, Holyrood, and Subang series. However, the yields on Munchong and Selangor series agreed with their respective high and low class rankings. Those soils derived from argillaceous shales (Durian, Munchong, and Melaka) and sandstones (Serdang) were generally found in the upper yield category while those that were derived from riverine alluvium (Holyrood), organic enriched alluvial deposits (Subang), and marine alluvium (Selangor and Harimau) were low yielding soils.

Significant differences in mineral concentrations in Hevea leaves were found among trees growing on different soil series (Table 25). With the exception of K and Ca, most mineral concentrations in the leaves, if based on standards for other economic crops, were low and possibly deficient. However, from a general inspection of the data there seemed to be no set trend to infer that a specific nutrient (or nutrients) was limiting Hevea production. If latex yield is not directly related to a single nutrient factor, in short or in excess supply, it is likely that interactions between nutrients or nutrient ratios would be more important considerations. Several investigators have stressed the significance of maintaining certain nutritional balances such as K/Mg, Mg/Mn, and Mg/P ratios in Hevea (Bolle-Jones, 1954b; and Pushparajah, 1969).

Table 24. Latex production, average tree girth, and rainfall, for Hevea clone RRIM 600 in 1977 and class rankings for Hevea production of nine soils.

Soil series	Latex yield	Tree girth	Rainfall	Class ranking [†]
	kg/ha	cm	mm	
Durian	2030	62	1975	IV
Serdang	1987	69	2128	III
Munchong	1979	69	2645	Ia
Melaka	1744	80	2440	IV
Subang	1611	71	1848	IIb
Holyrood	1610	62	2544	III
Selangor	1586	70	1630	V
Harimau	1440	60	1969	IIa
Rengam	-----	NA [‡]	-----	Ib

[†]Pushparajah and Tan (1972).

[‡]NA--Information not available.

Table 25. Average mineral contents in leaves of Hevea clone RRIM 600 collected in 1977 from nine soils.

Soil series	Mineral content									
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	Al
	-----%			-----ppm-----						
Durian	0.14d [†]	1.93abc	0.92a	0.23b	4cd	22cde	128b	2c	13cd	4c
Serdang	0.17c	1.98ab	0.63cd	0.24b	5bc	19de	186a	3c	21b	6c
Munchong	0.15d	1.97ab	0.78bc	0.20cd	8ab	23cd	77c	8c	14c	8c
Melaka	0.13d	2.05a	0.80abc	0.24b	5bc	14ef	132b	2c	12cd	5c
Subang	0.14d	1.74cd	0.61d	0.18de	2d	7f	24d	2c	15c	2c
Holyrood	0.18c	1.37e	0.71bcd	0.23b	9a	29bc	34d	52a	10d	33ab
Selangor	0.22a	1.79bcd	0.64cd	0.28a	10a	31b	112b	64a	29a	49a
Harimau	0.17c	1.73d	0.76bc	0.17e	10a	42a	30d	35b	20b	37ab
Rengam	0.20b	1.36e	0.84ab	0.22bc	9a	25bcd	71c	58a	13cd	24ab

[†]Means within column followed by same letter are not significantly different at 0.05 level by DMRT.

Among the macronutrients, P concentration in the leaves was observed to be in the low or deficient range except for soils of the Selangor and Rengam series (Table 25). Phosphorus content in the soil (by DA extractions) did not correlate well with the leaf P for soils such as Melaka and Selangor series (Table 15). The K and Ca concentrations in the leaves were adequate to high indicating that the soil reserves or the fertilization programs were providing these nutrients. Correlations between these two minerals in the soils and leaves were generally negative (discussed in later section); this suggests that these two elements are highly mobile in the soil and that fertilization rates would correlate better with leaf concentrations than would soil levels. The Mg content of the leaves was in the sufficient range except for Hevea grown on the Subang and Harimau series. Correlation between leaf and soil Mg contents was generally poor.

Although micronutrient requirements of Hevea have not been well determined, the levels found in the leaves were probably adequate except on the Subang soil, where levels of Cu, Zn, and Mn were very low relative to other economic crops (Table 25). Extractable soil micronutrient contents did not correlate well with the leaf concentrations (Table 15). Soils derived from riverine or marine alluvium such as Holyrood, Selangor, and Harimau series were found to produce adequate levels of Cu and Fe in the leaves but on soils developed from argillaceous shales (except for Cu in Munchong) and sandstones, leaf levels of Cu and Fe were relatively low. Concentrations of Cu in Hevea leaves on Durian, Serdang, and Melaka series usually tend to fall below the sufficiency level (Table 25). Iron concentrations in Hevea leaves from these soils and

Munchong were also possibly within the deficient range and seemed to be related to the Al content found in the leaves. However, the role of Al in Hevea trees has not been fully investigated.

Manganese content in the leaves was generally within the range of adequate to high on most soils derived from argillaceous shales (Durian, Melaka, and Munchong) and sandstones (Serdang) but deficient on soils derived from riverine, organic enriched, and marine alluvial deposited (Holyrood, Subang, and Harimau) parent materials. Leaf Mn tends to be well correlated with the extractable soil Mn.

With the exception of Hevea leaves obtained from Serdang, Selangor, and Harimau series, B concentrations were found to be relatively low. Soils derived from marine and older alluvium (Selangor and Harimau) were usually well supplied with B, and this proved to be true in this study (Table 18). According to the B sufficiency level determined by Bolle-Jones (1954a), B deficiency would likely occur at a concentration of 10 ppm or less. Such conditions were found only on Holyrood soil.

Effect of Munchong and Holyrood Soils on Clones

According to the 1977 average production records, Hevea clone RRIM 600 produced the highest yield on Munchong series, while clone PB 5/51 was the highest producer on Holyrood soil (Table 26). Of the four Hevea clones studied, RRIM 605 was the poorest performer on Munchong soil. Unfortunately, yield comparisons could not be made on clones RRIM 605 and GT 1 because yield records from Holyrood series were not available. The overall 1977 yields based on the available records were higher on Munchong than Holyrood soils.

Table 26. Average mineral concentrations in leaves and 1977 latex yields of four Hevea clones on Munchong and Holyrood soils.

Clones	Mineral content										Latex yield
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	A1	
	----- % -----										
	----- ppm -----										kg/ha/yr
	<u>Munchong</u>										
RRIM 600	0.15bc [†]	1.97b	0.78a	0.20a	8a	23a	77b	8a	14a	8b	1979
RRIM 605	0.14c	1.92c	0.79a	0.21a	8a	23a	140a	2b	12b	5c	1359
PB 5/51	0.16b	2.28a	0.40b	0.16c	7a	23a	46c	7a	14a	9a	1479
GT 1	0.19a	2.16ab	0.54b	0.18b	8a	32a	37c	8a	13ab	7b	1582
	<u>Holyrood</u>										
RRIM 600	0.18a	1.37c	0.71c	0.23b	9a	29a	34d	52b	10b	33b	1610
RRIM 605	0.14c	1.68a	1.34a	0.16c	10a	28a	159b	11c	17c	18c	--
PB 5/51	0.14c	1.62a	0.48d	0.13d	10a	23a	57c	60b	15a	78a	1557
GT 1	0.16b	1.51b	1.12b	0.32a	8a	24a	236a	80a	6c	69a	--

	<u>Average of four clones</u>										
Munchong	0.16a	2.08a	0.63b	0.19b	8a	25a	75b	6b	13a	7b	1600
Holyrood	0.16a	1.55b	0.91a	0.21a	9a	26a	121a	51a	10b	50a	1584

[†]Means within column segment followed by same letter are not significantly different at 0.05 level by DMRT.

Differences in mineral contents among clones were significant except for Cu and Zn as discussed earlier. The two soil series also had significant effects on mineral concentrations in tissue (Table 26). Higher K and consequent lower Ca and Mg levels in leaves produced on the Munchong soil are certainly related to the general characteristics of these two soils. Other differences are not so clear cut, as can be seen from Table 27. There was a wide difference in the mineral composition of the soils for each clone even when the clones were growing on the same soil series. In fact, differences between soil series were not as great as those between soils of the same series. It is assumed that much of this variation is the result of different fertilizer programs. Since the variations in extractable soil nutrients are large, it would be very difficult to distinguish between clonal (genetic) differences and differences caused by available soil minerals. Clone GT 1 was a high P accumulator on the Munchong series where extractable P is relatively high but on the Holyrood series extractable P is only one-third the level found under the other clones, yet leaf P is at the second highest level. Likewise, extractable Al in the Holyrood series varied by a factor of 14 which may influence P, Al, Fe, and Mn uptake far more than genetic factors.

The data establish very significant differences in the mineral contents of the leaves of Hevea from different clones. Unfortunately for these observations, differences within a soil series, largely attributed to management and fertilizer practices, were so great that it was not possible to attribute the differences directly to clonal or soil mineral differences.

Table 27. Some chemical properties and mineral contents (extracted by DA) of Munchong and Holyrood soils from 0-15 cm horizon as related to Hevea clone grown.

Hevea clone	pH (H ₂ O)	Organic matter	Mineral content										
			P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	Al	
			-----ppm-----										
		%											

Annual Variation of Mineral Contents of Hevea Tissues

The purpose of this investigation was to obtain evidence on the degree of variation in mineral concentrations in Hevea leaves, bark, and bark-scrap rubber from year to year. There is a need for more information in this area in order to better interpret tissue analysis data. Short term weather changes, short or long term fertilization responses, and annual latex production are among the factors that may cause variation in the mineral contents of Hevea tissues. This investigation examined variations in mineral concentrations of (1) three Hevea clones, namely, RRIM 605, PB 5/51, and GT 1, grown on Holyrood and Munchong soils; and (2) Hevea clone RRIM 600 grown on nine different soil series. Hevea tissues from each sampling location were collected during the August to October periods of 1976 and 1977, and the differences in mineral contents for the two years examined. During the initial stage of sample preparation, leaf samples collected from the first year (1976) were destroyed by fire. Therefore only the results obtained from bark and bark-scrap rubber were used in this discussion.

Effect of Clonal Differences

Annual variations in mineral nutrient contents in bark and bark-scrap rubber among clones may be most appropriately discussed with the available annual fertilization records of each soil and clone as shown in Table 28. Examination of the bark mineral data (Table 29) reveals that significant annual variations in mineral concentrations were usually not related

Table 28. Annual fertilizer applications to two soils used for Hevea production by multiple clones.

Year	Nutrients supplied [†]			
	N	P	K	Mg
-----g/tree-----				
<u>Munchong</u>				
<u>Clone RRIM 605</u>				
1976	25	14	28	4
1977	51	29	64	-
<u>Clone PB 5/51</u>				
1976	163	36	135	-
1977	136	28	135	-
<u>Clone GT 1</u>				
1976	-----Nil-----			
1977	57	78	71	8
<u>Holyrood[‡]</u>				
<u>Clone PB 5/51</u>				
1976	34	19	42	5
1977	68	38	85	11

[†] Nutrients supplied as a formulated fertilizer mixture.

[‡] Fertilization record for other clones on Holyrood series not available.

Table 29. Annual variation in mineral contents of bark for three Hevea clones grown on Munchong and Holyrood soils.

Year	Mineral content									
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	Al
	ppm	-----%	-----	-----	-----	-----	-----	-----	-----	-----
<u>Munchong</u>										
<u>Clone RRIM 605</u>										
1976	714a [†]	1.05b	2.98b	0.26b	8a	44a	209a	8a	3a	29b
1977	699a	1.31a	3.22a	0.32a	7a	41a	167b	12a	4a	46a
<u>Clone PB 5/51</u>										
1976	578a	1.05a	2.83b	0.12a	6a	52a	126a	18a	3a	21a
1977	585a	0.80b	2.97a	0.13a	6a	51a	106b	27a	4a	16a
<u>Clone GT 1</u>										
1976	597b	1.06a	3.24b	0.13a	8a	61a	115a	30b	3a	271b
1977	648a	0.96a	3.42a	0.13a	8a	55a	96b	42a	3a	407a
<u>Holyrood</u>										
<u>Clone RRIM 605</u>										
1976	413b	1.45a	4.71a	0.12a	5a	45a	229a	20b	6a	88b
1977	747a	1.22b	4.67a	0.11a	4a	42a	178b	33a	3b	149a
<u>Clone PB 5/51</u>										
1976	771a	1.13a	2.37a	0.10a	9a	40a	93a	10a	3a	39a
1977	771a	0.86b	2.40a	0.10a	10a	39a	79b	11a	4a	49a
<u>Clone GT 1</u>										
1976	533a	1.11a	3.99a	0.24a	4a	54a	308a	9a	5a	46b
1977	517a	0.82b	3.91a	0.25a	4a	52a	267b	15a	6a	74a

[†] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMR.

directly to the fertilizers applied for that particular year or the previous year. This is evident for most elements analyzed in the bark, including P, K, and Mg, where fertilizer variables were present. Previous investigations concluded that bark mineral analyses could be used to detect responses to fertilizer applications containing P and K, almost as satisfactorily as those from the laminae (Bollee-Jones, 1957d). From limited data on fertilizer applications (Table 28), only clone GT 1 on Munchong soil responded positively to added P, as indicated by the bark P concentrations. Only clone RRIM 605 seemed to respond positively to K application whereas clone PB 5/51 on both Munchong and Holyrood soil responded negatively to K applications as evidenced by reduced K concentrations in the bark. None of the clones on any soils exhibited a positive response to applied Mg while a negative response was obtained for clone RRIM 605 on Munchong soil.

Annual variations in other mineral concentrations in the bark such as Ca, Mn, Fe, and Al may be related, in some situations, to the indirect effect of fertilizer applications. Since none of these elements were supplied directly as a nutrient, the effect of pH changes, nutrient interactions, fertilizer contaminants, or "dilution" effects could become major factors causing significant annual variations of these elements. This can be illustrated by the increase in bark concentrations of Ca for clones RRIM 605 and GT 1 on Munchong soils possibly was a result of increased P fertilizer applications during 1977. Among micronutrients, Mn was most variable between years; however, from the limited data it is not possible to attribute these variations to

acidifying effects of fertilizers or to dilution effects from stimulated growth.

Annual variation of mineral concentrations in bark-scrap rubber (Table 30) were similar to that observed in the bark, and again could not be directly related to fertilizer applications. The above evidence suggests that annual mineral differences for many elements in bark and bark-scrap rubber did not represent a simple fertilizer response. Only Cu among the micronutrients exhibited significant variation in bark-scrap rubber. The limited data indicate an increase in Cu concentrations accompanies a general increase in fertilization rate. These limited observations would indicate that mineral contents of bark and bark-scrap rubber did not respond promptly to fertilizer applications. The high P fixing power of these soils could be a factor in delayed response to P fertilization but delayed response to N or K application was not likely. Unfortunately, due to insufficient information on fertilizer records for all clones observed, general conclusions cannot be drawn from the responses of these clones.

Effect of Different Soils

The objective of this study was similar to that of last section except that the effect of different soils on annual variation in mineral contents in bark and bark-scrap rubber of a single Hevea clone, RRIM 600, was investigated. These effects were also related to fertilizer applications on five soil series where records were available (Table 31). Data on mineral concentrations in bark and bark-scrap rubber, presented in Tables 32 and 33, respectively, showed that clonal variations

Table 30. Annual variation in mineral contents of bark-scrap rubber for three Hevea clones grown on Munchong and Holyrood soils.

Year	Mineral content									
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	Al
	ppm	-----	%-----	-----	-----	-----	-----	-----	-----	-----
<u>Munchong</u>										
<u>Clone RRIM 605</u>										
1976	825a [†]	1.08b	2.86b	0.20a	5a	49a	287a	6a	13a	13a
1977	819a	1.31a	3.07a	0.19a	7a	48a	186a	7a	9a	20a
<u>Clone PB 5/51</u>										
1976	741a	0.70a	2.39a	0.13a	3b	55a	101a	12a	5a	12a
1977	651b	0.54b	2.40a	0.11a	6a	48a	96a	11a	9a	13a
<u>Clone GT 1</u>										
1976	626a	0.84b	3.27b	0.15a	4b	66a	88a	24a	11a	121b
1977	616a	0.96a	3.79a	0.16a	7a	62a	91a	21a	7a	157a
<u>Holyrood</u>										
<u>Clone RRIM 605</u>										
1976	1037a	1.05a	3.91a	0.14a	3a	45a	162a	9a	6a	41b
1977	962b	1.07a	3.87a	0.12a	5a	46a	156a	8a	9a	67a
<u>Clone PB 5/51</u>										
1976	971b	0.91a	2.50b	0.11a	5b	49a	78a	11a	6a	23a
1977	1058a	0.87a	2.88a	0.12a	9a	46a	81a	11a	9a	33a
<u>Clone GT 1</u>										
1976	336a	0.95a	4.18b	0.33a	1a	27a	165a	2a	2a	1a
1977	327a	0.92a	4.55a	0.38a	1a	26a	160a	2a	2a	0a

[†] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMRT.

Table 31. Annual fertilizer applications to soils used for Hevea production of clone RRIM 600.

Year	Nutrients supplied [†]			
	N	P	K	Mg
-----g/tree-----				
	<u>Serdang</u>			
1976	182	24	50	-
1977	64	87	50	-
	<u>Melaka</u>			
1976	85	17	85	7
1977	51	29	64	8
	<u>Munchong</u>			
1976	34	19	42	5
1977	34	19	42	5
	<u>Holyrood</u>			
1976	43	24	50	-
1977	43	87	50	-
	<u>Subang</u>			
1976	57	108	71	8
1977	74	45	98	-

[†]Nutrients supplied as a formulated fertilizer mixture.

Table 32. Annual variation in mineral contents of bark from Hevea clone RRIM 600 grown on nine soil series.

Year	Mineral content									
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	Al
	ppm	-----%	-----	-----	-----	-----	-----	ppm	-----	-----
<u>Durian</u>										
1976	538a [†]	0.78a	2.42b	0.13a	6a	52a	148a	14b	2a	127b
1977	455b	0.86a	3.08a	0.14a	5a	47a	147a	27a	2a	522a
<u>Serdang</u>										
1976	444a	1.26a	2.80a	0.13b	5a	40a	396a	67b	2a	1110a
1977	406a	0.96b	2.25b	0.22a	5a	19b	209b	134a	3a	204b
<u>Munchong</u>										
1976	583a	1.04a	2.62b	0.13b	9a	50a	150a	11b	2a	59b
1977	591a	1.04a	3.03a	0.19a	7a	43a	114b	32a	4a	132a
<u>Melaka</u>										
1976	514a	0.55b	2.73a	0.16a	8a	37a	205a	14b	2a	167a
1977	422b	0.98a	2.32b	0.10b	7a	22b	124b	34a	2a	97b
<u>Subang</u>										
1976	603a	1.11a	3.07b	0.13b	4a	30a	97a	18a	3a	88a
1977	614a	0.74b	3.35a	0.16a	5a	28a	70b	19a	1a	84a
<u>Holyrood</u>										
1976	497b	1.36a	3.48a	0.15a	6a	45a	202a	14a	4a	37b
1977	636a	0.88b	3.39a	0.15a	6a	42a	143b	22a	5a	97a
<u>Selangor</u>										
1976	737b	0.85a	2.65a	0.21a	6a	33a	167a	5a	2a	3a
1977	857a	0.73a	2.40b	0.20a	6a	36a	157a	9a	6a	8a
<u>Harimau</u>										
1976	469a	1.20a	2.19a	0.13a	4a	55a	58a	24b	0	56b
1977	477a	0.75b	2.09a	0.11a	6a	59a	40a	45a	2a	667a
<u>Rengam</u>										
1976	589a	0.81b	2.51a	0.10a	6a	36a	87a	13b	2a	98a
1977	579a	1.25a	2.42a	0.11a	4a	36a	76a	29a	6a	72a

[†] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMR.

Table 33. Annual variation in mineral contents of bark-scrap rubber from Hevea clone RRIM 600 grown on nine soil series.

Year	Mineral content									
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B	Al
	ppm	-----%	-----	-----	-----	-----	-----	-----	-----	-----
<u>Durian</u>										
1976	964a [†]	0.52b	1.58b	0.14a	5a	38a	125a	10a	6a	37b
1977	480b	0.68a	2.53a	0.16a	5a	45a	121a	14a	5a	257a
<u>Serdang</u>										
1976	511b	0.79b	2.26a	0.16a	4a	36a	263a	12a	10a	423a
1977	654a	0.96a	2.25a	0.14a	5a	24b	204a	12a	6b	170b
<u>Munchong</u>										
1976	779a	0.84b	2.29b	0.16a	7a	59a	127a	12a	11a	30b
1977	696b	0.97a	2.75a	0.16a	7a	48a	144a	13a	8b	61a
<u>Melaka</u>										
1976	638a	0.68b	2.25a	0.17a	6a	47a	135a	9a	8a	21a
1977	643a	0.98a	1.64b	0.13a	5a	26b	123a	11a	8a	47a
<u>Subang</u>										
1976	884a	0.43a	1.60a	0.11a	3a	24a	37a	10a	3a	39b
1977	745b	0.44a	1.86a	0.14a	4a	25a	46a	17a	1a	73a
<u>Holyrood</u>										
1976	773a	0.90a	3.13b	0.19a	5a	43a	116a	18a	2b	20a
1977	747a	0.89a	3.60a	0.22a	5a	39a	110a	7a	7a	36a
<u>Selangor</u>										
1976	635b	0.88a	2.44a	0.24a	2a	26a	140a	3a	12a	25a
1977	991a	0.72b	2.39a	0.24a	5a	35a	138a	2a	3b	0
<u>Harimau</u>										
1976	637a	0.71a	1.79a	0.20a	3a	46a	36a	4a	2a	17b
1977	606a	0.75a	1.89a	0.16a	6a	59a	32a	11a	3a	253a
<u>Rengam</u>										
1976	790a	0.99a	2.52a	0.17a	5a	46a	80a	9a	13a	37a
1977	844a	0.97a	2.04b	0.17a	4a	39a	66a	7a	2b	47a

[†] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMR.

between years did not always follow simple changes in fertilization practices. Addition of P in fertilizers was positively related to P in Hevea bark on Holyrood soils; however, a negative response was obtained for Melaka, and for other soils, no response was obtained. Levels of K in bark were negatively related to addition of K fertilizers on Serdang, Melaka, Holyrood, and Subang soils. The effect of Mg fertilizer applications was erratic and usually not positively related to Mg content in the bark. Micronutrient data were equally inconsistent. Annual variations in the bark-scrap rubber mineral concentrations usually did not show any better correlation with fertilizer additions than the bark. These data supplied additional evidence indicating that annual fertilizer applications were not satisfactorily reflected by changes in mineral contents of bark and bark-scrap rubber. It was possible that some fertilizer nutrients were not promptly utilized by Hevea and a response indicated by a mineral concentration in bark or bark-scrap rubber would not be observed in one season.

Furthermore, latex was being removed from these trees almost continuously from time of fertilization to the time these samples were taken. Since the mineral contents of latex were relatively high, judging from levels in bark-scrap rubber, it was possible that extra minerals supplied in fertilizer had been removed in the harvested latex. One could even speculate that fertilization could on some occasions stimulate excessive losses of minerals in an increased latex flow, which could result in negative correlation of minerals in the tissues with fertilization practices.

Interrelationships Between Extractable Soil
Minerals and Hevea Tissues

Correlations Between Mineral Contents in Soils and Hevea Tissues

Correlation coefficients between mineral contents of nine soils extracted by three different methods and Hevea tissues from four clones are presented in Table 34. There were no consistent trends in correlation between P content in the leaves and the soils. Failure to observe positive correlations may be linked to different systems of P fertilization which have resulted in inconsistent soil surface distribution, as discussed earlier. A significant correlation was found between P content of Hevea leaves and soil P content at the 15-30 cm depth, taken from the tree-row and inter-row areas and extracted by DA and EDTA-TEA methods, respectively. This correlation suggests active uptake of P from soils at this depth. Soong (1971) studied the distribution of active feeder roots of Hevea and found that most were located in the surface horizon. Significant correlation between P content in leaves with soils at the 15-30 cm depth suggests the possibility of the existence of some mechanisms of P absorption other than the active feeder roots. Marx (1972) reported the role of ectomycorrhizae in the absorption and accumulation of various elements, such as N, P, K, and Ca, which were translocated to host plants. Presence of mycorrhizae in Hevea roots and their role in mineral absorption and translocation needs to be confirmed. Other correlations with Hevea leaf tissues were negative or inconclusive except that strong positive correlations were shown for Mn for all extractants and all soil samples and for Mg for all but one extractant-soil combination.

Table 34. Correlation coefficients between minerals extracted from nine soil series by three methods and Hevea tissues from four clones.

Hevea tissue	Tree-row				Inter-row					
	0-15 cm		15-30 cm		0-15 cm			15-30 cm		
	DA [†]	EDTA [‡]	HCl [§]		DA	EDTA	HCl	DA	EDTA	HCl
Phosphorus										
Leaves	0.068 [¶] NS [#]	-0.164 NS	-0.040 NS	0.303 0.04	-0.032 NS	-0.125 NS	-0.321 0.03	0.130 NS	0.320 0.03	-0.027 NS
Bark	0.343 0.02	0.048 NS	0.302 0.04	0.165 NS	0.272 NS	0.064 NS	0.368 0.01	0.018 NS	0.156 NS	0.126 NS
Bark- scrap rubber	0.333 0.02	0.109 NS	0.169 NS	0.183 NS	0.386 0.007	-0.013 NS	0.138 NS	-0.113 NS	0.221 NS	-0.004 NS
Potassium										
Leaves	-0.054 NS	-0.334 0.02	-0.115 NS	-0.141 NS	-0.277 NS	-0.123 NS	0.057 NS	-0.010 NS	-0.248 NS	0.029 NS
Bark	-0.355 0.01	-0.352 0.01	-0.352 0.01	-0.365 0.01	-0.302 0.01	-0.404 0.004	-0.362 0.01	-0.377 0.008	-0.433 0.002	-0.465 0.001
Bark- scrap rubber	-0.568 0.0001	-0.420 0.003	-0.365 0.01	-0.560 0.0001	-0.534 0.0001	-0.502 0.0003	-0.482 0.0005	-0.543 0.0001	-0.473 0.001	-0.494 0.0004

Table 34. (Continued)

Hevea tissue	Tree-row					Inter-row				
	0-15 cm		15-30 cm			0-15 cm		15-30 cm		
	DA ⁺	EDTA ⁺	HCl ⁺	DA	EDTA	HCl	DA	EDTA	DA	HCl
Calcium										
Leaves	-0.294 [†] 0.04 [‡]	--	0.126 NS	-0.265 NS	--	-0.031 NS	-0.108 NS	--	-0.189 NS	-0.019 NS
Bark	-0.295 0.04	--	0.257 NS	-0.237 NS	--	0.058 NS	-0.191 NS	--	-0.188 NS	-0.038 NS
Bark- scrap rubber	-0.178 NS	--	0.131 NS	0.441 0.002	--	-0.284 0.05	-0.133 NS	--	-0.328 0.02	-0.196 NS
Magnesium										
Leaves	0.341 0.02	0.310 0.03	0.346 0.02	0.367 0.01	0.395 0.006	0.367 0.01	0.388 0.006	0.396 0.005	0.386 0.007	0.372 0.01
Bark	0.099 NS	0.129 NS	0.095 NS	0.166 NS	0.143 NS	0.122 NS	0.142 NS	0.127 NS	0.148 NS	0.122 NS
Bark- scrap rubber	0.191 NS	0.243 NS	0.174 NS	0.196 NS	0.234 NS	0.181 NS	0.252 NS	0.268 NS	0.236 NS	0.233 NS

Table 34. (Continued)

Hevea tissue	Tree-row					Inter-row				
	0-15 cm			15-30 cm		0-15 cm			15-30 cm	
	DA [†]	EDTA [‡]	HCl [§]	DA	EDTA	HCl	DA	EDTA	HCl	HCl
Leaves	-0.107 [¶] NS [#]	-0.173 NS	-0.297 0.04	-0.014 NS	-0.223 NS	-0.316 0.03	0.008 NS	-0.037 NS	-0.069 NS	-0.314 0.03
Bark	0.485 0.001	0.411 0.004	0.491 0.0004	0.193 NS	0.260 NS	0.271 NS	0.273 NS	0.266 NS	0.294 0.04	0.157 NS
Bark-scrap rubber	0.443 0.002	0.309 0.03	0.343 0.02	0.231 NS	0.263 NS	0.219 NS	0.415 0.003	0.363 0.01	0.306 0.03	0.157 NS
Leaves	-0.038 NS	-0.291 0.04	-0.120 NS	-0.062 NS	-0.202 NS	0.022 NS	0.050 NS	-0.075 NS	0.145 NS	-0.189 NS
Bark	-0.138 NS	-0.229 NS	-0.187 NS	0.008 NS	-0.116 NS	0.038 NS	-0.111 NS	-0.282 0.05	-0.155 NS	-0.277 NS
Bark-scrap rubber	-0.032 NS	-0.130 NS	0.010 NS	0.096 NS	-0.149 NS	0.001 NS	-0.040 NS	-0.058 NS	-0.030 NS	-0.050 NS
										0.033 NS

Copper

Zinc

Hevea bark P was positively correlated with extractable P in the surface soils extracted by DA and 5 N HCl. Strong negative correlations with K were obtained for all trials in which strong positive correlations were observed for Mn. The Cu levels in the 0-15 cm horizon of the tree-row were positively correlated with Cu levels in the leaves.

Mineral content of bark-scrap rubber was strongly negatively correlated with K, positively correlated with P in two trials, exhibited positive and negative correlations with Ca, exhibited seven positive correlations with Cu, and was positively correlated with Fe in both HCl extractants.

The wide variability in B contents of the nine soils and four Hevea clones resulted in mostly negative and non-significant correlations between Hevea tissues and soil extractable B by hot water (Table 35). The only significant negative correlation was found between B in the 15-30 cm horizon of the tree-row and the bark tissue. However, with some individual clones and soil series, a good correlation was observed between soil extractable B and Hevea leaves (as discussed previously).

It appears that a wide variety of extractants and soil sampling sites will provide good correlations between soil and leaf contents of Mg and Mn or between soil and bark contents of Mn. A few additional positive or negative correlations were found but they were not indicative of easily recognized trends. It was possible that additional meaningful correlations will be found only when data are limited to soil series and method(s) of fertilizer application as well as selection of sampling site and extracting solution. Positive significant correlations of Hevea tissues and highly soluble fertilizer elements such as K, which leached readily from the soil, may be possible only when the quantities of K

Table 35. Correlation coefficients between B extracted from nine soils[†] and B content of Hevea tissues from four clones.

Hevea tissue	Tree-row		Inter-row	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Leaves	0.167 [‡] NS [§]	0.159 NS	0.262 NS	0.209 NS
Bark	-0.254 NS	-0.305 0.03	-0.123 NS	-0.140 NS
Bark-scrap rubber	-0.258 NS	0.071 NS	-0.191 NS	-0.048 NS

[†]Hot water extractable B.

[‡]Correlation coefficient (r).

[§]Probability $|r|$, under H_0 : $\rho = 0$.

applied as fertilizer are considered. However, significant linear correlations of leaf and total soil K have been reported when significant correlations of leaf and exchangeable K were not found (Shorrocks, 1965). Failure to obtain strong positive correlations of leaf and soil P extracted by 5 N HCl indicates that, despite relatively large quantities of P removed by this extractant, much of the P extracted was from forms unavailable to plants.

Correlations Between Minerals in Hevea Tissues

Correlation coefficients between minerals within Hevea leaves, bark, and bark-scrap rubber are shown in Tables 36 to 38, respectively. Data shown in these tables indicate that correlation trends between minerals in one tissue were not necessarily followed in other tissues. A negative correlation was observed between Ca and K in the leaves which suggest an antagonistic effect of these elements. Bolle-Jones (1954a) reported that Ca or Mg deficient Hevea seedlings tend to accumulate K in the leaves. However, an opposite effect was noted in a positive correlation of Ca with K in the bark-scrap rubber. A significant, positive, correlation was also observed between Ca and P in the Hevea bark.

Magnesium in leaves were significantly and positively correlated with P but in bark-scrap rubber the same correlation was negative. Bolle-Jones (1954b) reported that additions of phosphate to Hevea seedlings frequently enhanced Mg concentration of the laminae. He also found that in Mg deficient leaves the Ca concentrations increased markedly. The negative correlation found between Mg and Ca in leaves seemed to indicate a potential for Mg deficiency in some trees used in

Table 36. Correlation coefficients between minerals in Hevea leaves from four clones and nine soil series.

Mineral content [†] in leaves	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
K	-0.216 [‡] NS [§]								
Ca	-0.168 NS	-0.369 0.01							
Mg	0.375 0.01	-0.201 NS	-0.335 0.02						
Cu	0.406 0.004	-0.281 0.05	0.126 NS	-0.064 NS					
Zn	0.504 0.0003	-0.195 NS	0.095 NS	-0.037 NS	-0.830 0.0001				
Mn	-0.151 NS	-0.057 NS	0.591 0.0001	0.598 0.0001	-0.007 NS	-0.131 NS			
Fe	0.514 0.0002	-0.705 0.0001	0.061 NS	0.364 0.01	0.512 0.0002	0.375 0.009	0.093 NS		
Al	0.247 NS	-0.571 0.0001	0.042 NS	0.170 NS	0.511 0.0002	0.353 0.01	0.131 NS	0.884 0.0001	
B	0.435 0.002	0.162 NS	-0.457 0.0001	0.043 NS	-0.004 NS	0.162 NS	-0.166 NS	0.060 NS	0.062 NS

[†]Number of observations = 48.[‡]Correlation coefficient (*r*).[§]Probability $|r|$, under H_0 : $\rho = 0$.

Table 37. Correlation coefficients between minerals in Hevea bark from four clones and nine soil series.

Mineral content in bark [†]	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
K	0.096 [‡] NS [§]								
Ca	0.285 0.05	0.243 NS							
Mg	0.028 NS	0.287 0.05	0.110 NS						
Cu	0.261 NS	0.049 NS	-0.323 0.03	-0.058 NS					
Zn	0.176 NS	-0.131 NS	0.325 0.02	-0.115 NS	-0.008 NS				
Mn	0.002 NS	0.236 NS	0.432 0.002	0.576 0.0001	-0.233 NS	-0.064 NS			
Fe	0.491 0.0004	0.032 NS	-0.230 NS	-0.051 NS	-0.118 NS	-0.317 NS	0.127 NS		
Al	-0.348 0.02	-0.174 NS	-0.082 NS	-0.270 NS	-0.047 NS	0.517 0.0002	-0.215 NS	0.273 NS	
B	0.282 0.05	-0.137 NS	-0.111 NS	0.125 NS	-0.158 NS	0.176 NS	0.080 NS	-0.271 NS	-0.433 0.002

[†]Number of observations = 48.[‡]Correlation coefficient (*r*).[§]Probability $|r|$, under H_0 : $\rho = 0$.

Table 38. Correlation coefficients between minerals in Hevea bark-scrap rubber from four clones and nine soil series.

Mineral content in bark scrap rubber†	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
K	-0.069 [‡] NS [§]								
Ca	-0.151 NS	0.618 0.0001							
Mg	-0.495 0.0003	0.335 0.02	0.500 0.0003						
Cu	0.427 0.003	0.128 NS	-0.124 NS	-0.482 0.001					
Zn	0.204 NS	0.079 NS	-0.039 NS	-0.332 0.02	0.763 0.0001				
Mn	-0.193 NS	0.315 0.03	0.382 0.007	0.300 0.04	0.025 NS	-0.094 NS			
Fe	-0.011 NS	-0.304 0.04	-0.026 NS	-0.023 NS	0.103 NS	0.318 0.03	-0.269 NS		
Al	-0.347 0.02	-0.136 NS	-0.069 NS	-0.145 NS	-0.124 NS	0.079 NS	0.451 0.001	0.162 NS	
B	-0.140 NS	0.096 NS	-0.100 NS	0.070 NS	0.276 NS	0.220 NS	0.326 0.02	-0.051 NS	0.194 NS

†Number of observations = 48.

‡Correlation coefficient (*r*).§Probability $|r|$, under H_0 : $\rho = 0$.

this study. The Mg levels in these leaves were found to be lower than the critical level (Table 26). A significant correlation was also found between Mg and K in the bark and bark-scrap rubber. Low Mg supply or excessive amounts of K or P could produce severe Mg deficiency symptoms which were associated with an elevated K/Mg ratio (Bolle-Jones, 1954b).

Leaf levels of Cu, Zn, Fe, and B were highly correlated with P. The positive correlation between these micronutrients and P in the leaves seems to indicate that these elements may be supplied as impurities when P were applied from fertilizers or that P fertilizer stimulated root uptake of these elements. A negative correlation was observed between Cu and Ca in the bark and between Cu and Mg in the bark-scrap rubber. Hence, an increase in Cu availability could reduce Ca concentration in the bark and Mg concentration in bark-scrap rubber.

A reverse trend in correlation was observed between Zn and Cu in both leaves and bark-scrap rubber. A highly negative correlation was noted between Zn and Cu in the leaves which indicates an interaction in uptake between these two elements. Millikan (1953) found that with Zn deficiency in alfalfa and subterranean clover, lowered Zn concentration in plants was accompanied by a marked increase in Cu concentration. Only Ca was significantly correlated with Zn in the bark.

Manganese correlations with Ca and Mg were most marked in this study; correlation coefficients were highly significant simultaneously in the three different tissues. Positive correlations between Mg and Mn have been previously reported by Beaufrils (1955). However, most studies with Hevea demonstrated the depressive effect of excessive Mg application resulting in induced Mn deficiency symptoms in the leaves (Bolton and Shorrocks, 1961 and Bolle-Jones, 1957c). The interrelationship

between Ca and Mn in the leaves of Hevea have been reported by Bolle-Jones (1954a). He stated that increased Ca concentration in the leaves was directly related to increased ash and Mn concentrations.

A negative correlation between Fe and K in both leaves and bark-scrap rubber was observed; the most significant effect ($r = -0.705$) was noted in the leaves. The depressive effect of restricted K supply on Fe content in Hevea had been confirmed; this effect was accompanied by a reduced chlorophyll content in the leaves (Bolle-Jones, 1954a). Positive correlations between Fe and P (in leaves and bark), Zn (in leaves and bark-scrap rubber), and Cu (in leaves) have been implicated earlier with the availability of these elements enhanced by the application of P fertilizers.

Among the mineral elements, only K was found to be negatively correlated with Al in the leaves. Effects of this interrelationship in Hevea had not been previously reported; however, this study indicated that high K concentration seemed to suppress Al accumulation in the leaves. This relationship is very highly significant despite the fact that only a small amount of Al was found in Hevea tissues. The fact that these soils were high in extractable and exchangeable Al would indicate that Hevea roots may be highly selective for K while strongly excluding Al.

Aluminum was also correlated with Cu, Zn, and Fe in the leaves. The high correlation obtained, especially with Fe ($r = 0.884$), indicated that the strongly acidic environment in Malaysian soils seemed to favor the availability of micronutrients for plant uptake. The negative correlation between Al and P in the bark and bark-scrap rubber suggested the role of P in suppressing the uptake of Al. There was considerable

evidence that differential Al tolerance among plant species and varieties was at least correlated with their ability to absorb and utilize P in the presence of excess Al (Jones, 1961; Foy and Brown, 1964).

In leaves, B was negatively correlated with Ca content. The effect of high Ca content in depressing B uptake in certain plants has been known (Fox, 1968). Correlations between B and P in the leaves and bark were also significant.

SUMMARY AND CONCLUSIONS

This study was conducted with the primary objectives of: (1) evaluating the fertility status, especially of micronutrients, of some soils commonly used for Hevea production in Malaysia; (2) assessing the distribution of plant nutrients within soil profiles; and (3) determining the relationships between mineral contents in soils and Hevea tissues.

Soils from nine series were collected from various plantations representing the major Hevea growing areas located along the west coast of Peninsular Malaysia. Soil samples were taken from the tree-row and inter-row and at 0-15 and 15-30 cm depths at each location. Profile samples from the inter-row of the same nine soil series were taken to represent genetic horizons determined by visual inspection. Usually four separate horizons were recognized in each profile and the average maximum depth of sampling was 130 cm.

Tissues from Hevea clone RRIM 600 were collected from the same nine soil series to determine the relationships between mineral contents in Hevea tissues and the soils. Tissues were taken from four Hevea clones on two contrasting soil types, Munchong and Holyrood, and examined for the same purpose. Differences in mineral contents in Hevea tissues among the four clones and between the two soil series were also investigated. These Hevea clones were sampled in 1976 and 1977 in order to study the annual variation in their mineral contents.

Chemical properties of the soils were investigated, including the use of three extractants to determine ease of soil mineral removal. Boron content of the soils was determined by hot water extraction. The mineral composition of the Hevea leaves, bark, and bark-scrap rubber was also determined.

The chelate reagent EDTA-TEA generally extracted the least amount of minerals from the soils; however, when soils were high in Fe, the extractable P by this method was usually high. Significantly higher concentrations of P, Cu, Zn, Mn, Fe, and Al were extracted by 5 N HCl. The DA reagent was generally equal to 5 N HCl in Ca and Mg extractions, and intermediate for other elements except K. The DA appeared to extract equal amounts of Ca and more K than the 5 N HCl extractant; however, this was probably an artifact of atomic absorption and flame emission procedures, respectively, in the HCl solution.

Soil mineral contents between tree-row and inter-row did not differ significantly at the same depth. Overall differences in mineral contents between the two depths, regardless of row, were only significant for P and Ca (by DA and 5 N HCl extraction), and for K by the DA extraction. Micronutrient contents such as Cu, Zn, Mn, and Fe did not differ significantly between rows; however, Zn and Mn exhibited a trend to relatively higher values in the inter-row.

Distribution of mineral contents within soil profiles generally indicated poor reserves for many mineral elements. Applications of phosphate fertilizers resulted in a P accumulation in the surface horizon. Because the soils are acidic and high in Fe and Al, downward movement of P was negligible. Relatively low levels of extractable K and Ca in soils fertilized with these elements indicated that these bases were lost

either by leaching or rapid utilization by the trees. Extractable micronutrients changed very little with soil depth except for the Selangor series where Cu and Zn increased in the 66-86 cm horizon. From the data accumulated it was concluded that a composite soil sample of the 0-15 cm horizon taken to represent row- and inter-row areas would accurately represent the soil in which Hevea is grown. Knowledge of the soil series sampled would be of additional help in estimating possible micronutrient reserves in the lower horizons.

The general fertility status of the nine Malaysian soils used in this study is comparatively low by the standards of most temperate soils. Differences in mineral contents among soil series were usually attributed to their clay minerals, quantity of clay and organic matter present, and the cultural management practices of each plantation. Extractable micronutrients in most of the soils were in a low-adequate range, except for Fe which was high. Geochemical effects on soil formation have strongly influenced the micronutrient reserves in these soils. Extractable Al was high for all soils, which is typical of soils from the humid tropics.

Levels of P, Mg, Cu, Fe, and B in the leaves of Hevea grown on a number of soils were below optimum levels reported by earlier workers. An increased latex production pattern was apparently related to higher Mn concentrations in the leaves. However, the data did not show a conclusive trend indicating that a specific nutrient (or nutrients) was involved directly in limiting latex yield. It is more likely that interactions between nutrients or nutrient ratios exert more influence on latex production.

Significant differences in leaf mineral contents were found among four Hevea clones. However, the wide variations in extractable minerals

observed within a soil series, largely attributed to management and cultural practices, make it impossible to make clear distinctions between the effects of clone and mineral contents of the soils on the mineral contents of Hevea tissue.

Observations on variations in mineral contents of bark and bark-scrap rubber sampled in successive years indicated that changes in mineral content were not consistent responses to fertilizer applications. Since bark and bark-scrap rubber did not prove to be good indicators to detect responses to fertilizer application, perhaps the conventional use of leaf tissue as a diagnostic tool is to be preferred.

Based on correlation studies, it appeared that a wide variety of extractants and soil sampling sites will provide good correlations between soil and leaf contents of Mg and Mn or between soil and bark contents of Mn. Correlations of other minerals in Hevea tissues and minerals extracted by the three extractants from soil samples taken from several sites were inconsistent or non-existent. It appeared that variations related to differences in soil series as well as kinds and methods of fertilizer application will limit good overall correlations for many of the elements studied.

Latex production data for 1977 was not in close agreement with the proposed soil suitability class ranking. Apparently the low suitability class rankings of some soil series are being largely overcome by cultural practices which include use of adapted clones, fertilizer, and drainage.

Tissue analyses of bark and bark-scrap rubber contained relatively high concentrations of micronutrients, especially Cu, Zn, and Mn. The long term effects of continuous crop removal plus macronutrient fertilization to increase latex production could result in an appreciable

depletion of these elements. Since the reserves of these elements appear to be quite limited in some of the soil series examined, there is a need to consider soil replenishment in order to maintain long term latex production.

APPENDIX

Table 39. Mineral contents extracted by DA of nine Malaysian soils used for Hevea production, as related to location of sampling.[†]

Soil series	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
	<u>Tree-row</u>								
Durian	3.4a [‡]	64a	42cd	11d	0.4a	0.8a	2.1d	393a	683cd
Serdang	5.2a	38a	91abc	14c	0.9a	1.6a	24.5a	173bcd	343d
Munchong	3.6a	32a	27d	6e	1.5a	1.1a	2.3d	266b	581cd
Melaka	0.5a	27a	42cd	6e	1.3a	0.6a	2.1d	225bc	386cd
Subang	4.4a	145a	140a	23b	0.2a	1.2a	3.4d	66d	2033a
Holyrood	11.0a	34a	46cd	6e	0.4a	0.8a	8.1c	139cd	501cd
Selangor	6.5a	65a	113ab	83a	0.2a	1.2a	16.1b	54d	1313b
Harimau	1.5a	38a	39cd	8de	0.4a	1.2a	1.3d	249b	670cd
Rengam	6.2a	54a	48bcd	9de	0.3a	0.8a	3.0d	218bc	730c
	<u>Inter-row</u>								
Durian	6.7a	52a	31bcd	11cd	0.4a	0.8b	2.4de	318ab	797cd
Serdang	2.7a	40a	84bc	13c	0.8a	3.0a	28.6a	213bc	343d
Munchong	1.2a	32a	18d	7e	1.3a	1.2b	2.2de	260ab	521cde
Melaka	0.3a	23a	28cd	7e	1.1a	0.9b	4.5d	230abc	408e
Subang	2.8a	129a	109a	25b	0.2a	1.7ab	3.8de	223bc	2093a
Holyrood	1.8a	29a	24cd	7e	0.4a	0.9b	7.0c	148c	510cd
Selangor	7.0a	70a	297a	126a	0.2a	1.4b	19.3b	45d	1453b
Harimau	1.6a	38a	30bcd	9de	1.5a	1.7ab	1.4e	361a	803c
Rengam	3.2a	22a	47bcd	8de	0.2a	0.6b	3.6de	187bc	690cde

[†]Each figure represents average values of 0-15 and 15-30 cm horizon.

[‡]Means within column segment followed by same letter are not significantly different at 0.05 level by DNMRT.

Table 40. Mineral contents extracted by EDTA-TEA (pH 7.3) of nine Malaysian soils used for Hevea production, as related to location of sampling.[†]

Soil series	Mineral content							
	P	K	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----								
	<u>Tree-row</u>							
Durian	5.7a [‡]	16a	3c	0.3a	0.5a	1.3c	148b	143ab
Serdang	0.8a	13a	5bc	0.6a	1.1c	13.2a	49bc	58b
Munchong	2.2a	8a	3c	1.0a	0.6a	1.3c	74bc	170ab
Melaka	5.0a	6a	3c	1.2a	0.5a	1.7c	70bc	305ab
Subang	19.1a	76a	7b	0.5a	1.1a	1.8a	335a	342ab
Holyrood	2.4a	19a	3c	0.2a	0.7a	4.5b	33c	68b
Selangor	5.4a	33a	49a	0.5a	0.7a	4.9b	72bc	380a
Harimau	0.6a	17a	3c	0.1a	0.6a	1.0c	41bc	72ab
Rengam	3.1a	19a	3c	0.3a	0.5a	1.2c	70bc	67b
	<u>Inter-row</u>							
Durian	0.4a	12a	4b	0.3a	0.8b	1.2c	108b	150a
Serdang	1.3a	13a	4b	0.5a	2.3a	26.7a	80b	45a
Munchong	1.8a	10a	2b	1.0a	0.8b	1.5c	68b	185a
Melaka	1.5a	4a	3b	0.7a	0.7b	3.0c	73b	362a
Subang	10.0a	44a	5b	1.0a	1.1ab	2.1c	375a	317a
Holyrood	0.8a	20a	3b	0.2a	0.8b	6.7b	34b	104a
Selangor	3.0a	33a	63a	0.4a	0.8b	7.7b	87b	370a
Harimau	0.9a	24a	3b	0.9a	0.7b	0.6c	39b	82a
Rengam	2.0a	11a	3b	0.2a	0.4b	1.4c	65b	63a

[†] Each figure represents average values of 0-15 and 15-30 cm horizon.

[‡] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMRT.

Table 41. Mineral contents extracted by 5 N HCl of nine Malaysian soils used for Hevea production, as related to location of sampling.[†]

Soil series	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
	<u>Tree-row</u>								
Durian	14.3bc [‡]	32a	32c	9c	0.6ab	1.3b	3.9ef	2860b	1227d
Serdang	10.9c	33a	7abc	8d	1.1ab	1.9ab	33.7a	1186e	385f
Munchong	39.3bc	17a	33c	7d	2.1a	1.3b	4.3f	1877c	1304d
Melaka	53.0ab	14a	54bc	9cd	2.4a	1.0b	6.7d	1976c	1027de
Subang	86.3a	71a	143a	27b	2.1a	2.3ab	6.3de	6073a	5600a
Holyrood	25.0bc	23a	63bc	4e	0.4b	2.1ab	12.4c	674f	1214d
Selangor	22.6bd	41a	119ab	90a	1.9a	2.5a	19.0b	1627d	3457d
Harimau	8.4c	25a	29c	4e	0.3b	1.6ab	2.0f	1185e	772e
Rengam	20.3bc	18a	44bc	9c	0.6ab	1.3b	3.3f	1860c	1737c
	<u>Inter-row</u>								
Durian	13.7ab	27a	29bc	12cd	0.8ab	1.2cd	4.0f	3367b	1477cde
Serdang	15.1ab	34a	65bc	8ef	1.1ab	3.6a	35.0a	1177e	385g
Munchong	20.3ab	20a	21c	7f	2.1a	1.9bcd	3.7f	1819d	1260ef
Melaka	24.5ab	12a	41bc	9de	2.1a	1.5cd	10.2d	2043c	1066f
Subang	50.6a	58a	94b	23b	2.3a	2.8ab	7.1e	6140a	5100a
Holyrood	4.1b	19a	43bc	4g	0.4b	1.5cd	13.6c	659f	1360de
Selangor	40.6a	45a	360a	150a	1.8ab	3.5a	28.6b	1727d	3773b
Harimau	17.2ab	53a	41bc	12c	1.9ab	2.5abc	2.0f	1773d	1600cd
Rengam	14.3ab	10a	42bc	8ef	0.3b	0.9d	4.0f	1793d	1730c

[†] Each figure represents average values of 0-15 and 15-30 cm horizon.[‡] Means within column segment followed by same letter are not significantly different at 0.05 level by DNMR.

Table 42. Mineral contents extracted by DA of nine Malaysian soils used for *Hevea* production, as related to depth of sampling. †

Soil series	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
					<u>0-15 cm</u>				
Durian	5.3a ‡	67a	43bc	12a	0.3a	0.8b	2.7bc	461a	723bcd
Serdang	4.2a	43a	97bc	14a	0.9a	3.0a	30.5a	197bcd	350e
Munchong	3.3a	41a	25c	7a	1.5a	1.1b	2.3c	256b	544b-e
Melaka	0.5a	24a	35bc	7a	1.1a	0.6b	3.1bc	229bc	378de
Subang	3.8a	140a	119b	24a	0.2a	1.4b	3.9bc	75de	2013a
Holyrood	11.2a	38a	52bc	8a	0.4a	0.9b	9.1b	118cde	489cde
Selangor	8.3a	70a	287a	104a	0.2a	1.5b	24.0a	24e	1703a
Harimau	1.9a	43a	33bc	9a	1.2a	1.9b	1.5c	291b	751bc
Rengam	5.6a	39a	51bc	9a	0.2a	0.7b	3.4bc	193bcd	780b
					<u>15-30 cm</u>				
Durian	4.8a	48a	30bc	9a	0.4a	0.8a	1.7c	250ab	757bc
Serdang	3.7a	36a	78abc	13a	0.8a	1.5a	22.6a	189abc	337d
Munchong	1.4a	24a	21c	6a	1.3a	1.3a	2.2c	269a	557cd
Melaka	0.3a	26a	36abc	7a	1.3a	0.9a	3.4c	227abc	416cd
Subang	3.3a	135a	131a	25a	0.2a	1.5a	3.3c	214abc	2113a
Holyrood	1.5a	25a	18c	5a	0.4a	0.8a	6.1bc	169bc	522cd
Selangor	5.1a	65a	123ab	105a	0.2a	1.1a	11.4b	76c	1063b
Harimau	1.2a	34a	37abc	8a	0.7a	1.1a	1.2c	320a	722c
Rengam	3.7a	37a	44abc	8a	0.3a	0.8a	3.2c	211abc	640cd

† Each figure represents average values of tree- and inter-row.

‡ Means within column segment followed by same letter are not significantly different at 0.05 level by DNMRT.

Table 43. Mineral contents extracted by EDTA-TEA (pH 7.3) of nine Malaysian soils used for Hevea production, as related to depth of sampling.[†]

Soil series	Mineral content							
	P	K	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----								
	0-15 cm							
Durian	2.9a [‡]	19a	4a	0.3a	0.8b	1.6c	171a	137ab
Serdang	1.3a	14a	4a	0.6a	2.3a	23.2a	71a	45b
Munchong	2.6a	11a	3a	1.2a	0.7b	1.6c	84a	182ab
Melaka	1.7a	5a	3a	1.0a	0.5b	2.5bc	84a	317ab
Subang	25.4a	54a	5a	0.6a	1.2ab	2.2bc	363a	293ab
Holyrood	0.7a	24a	3a	0.3a	0.8b	7.1b	40a	96b
Selangor	2.6a	29a	43a	0.7a	1.1ab	9.3b	95a	430a
Harimau	0.9a	23a	3a	0.7a	0.8b	0.9c	42a	84b
Rengam	2.2a	15a	3a	0.2a	0.4b	1.4c	80a	70b
	15-30 cm							
Durian	3.2a	10a	23a	0.3a	0.5a	1.0b	85a	157ab
Serdang	0.8a	11a	4a	0.5a	1.2a	16.7a	58a	58b
Munchong	1.4a	6a	2a	0.7a	0.7a	1.2b	57a	173ab
Melaka	4.8a	5a	3a	0.9a	0.7a	2.2b	59a	350ab
Subang	3.6a	66a	7a	0.8a	1.0a	1.7b	347a	365a
Holyrood	2.5a	15a	3a	0.2a	0.7a	4.1b	28a	76b
Selangor	5.5a	37a	69a	0.2a	0.5a	3.4b	64a	320ab
Harimau	0.6a	18a	3a	0.3a	0.6a	0.7b	37a	70b
Rengam	2.8a	15a	3a	0.3a	0.4a	1.1b	55a	60b

[†]Each figure represents average values of tree- and inter-row.

[‡]Means within column segment followed by same letter are not significantly different at 0.05 level by DNMRT.

Table 44. Mineral contents extracted by 5 N HCl of nine Malaysian soils used for *Hevea* production, as related to depth of sampling.[†]

Soil series	Mineral content								
	P	K	Ca	Mg	Cu	Zn	Mn	Fe	Al
-----ppm-----									
	<u>0-15 cm</u>								
Durian	19.7cd [‡]	33a	36bc	12a	0.7bc	1.3cd	4.7c	3000b	1317d
Serdang	13.5d	37a	75bc	9a	1.1abc	3.6a	38.7a	1179e	383e
Munchong	39.3bc	23a	30c	7a	2.3a	1.8cd	4.1c	1802c	1221d
Melaka	46.6bc	13a	46bc	9a	2.1ab	1.0d	8.2c	1787c	969d
Subang	78.2a	67a	116b	26a	2.1ab	2.3bc	8.1c	7067a	5267a
Holyrood	25.3cd	25a	76bc	5a	0.4c	1.7cd	15.5b	633f	1276d
Selangor	50.2b	45a	348a	108a	2.5a	3.3ab	33.0a	1627d	3977b
Harimau	14.7d	42a	33bc	9a	1.4abc	2.3bcd	2.1c	1559d	1160d
Rengam	22.4cd	16a	46bc	10a	0.4c	1.2cd	3.7c	1840c	1763c
	<u>15-30 cm</u>								
Durian	8.3bc	26a	26b	9a	0.7bc	1.2b	3.2d	3227b	1387cd
Serdang	12.5bc	31a	61ab	8a	1.0abc	1.9ab	30.0a	1184g	387e
Munchong	20.2b	14a	24b	2a	1.6ab	1.4b	3.9d	1893d	1344d
Melaka	33.3ab	13a	50ab	9a	2.3a	1.5ab	8.7bcd	2232c	1125d
Subang	58.7a	63a	121a	24a	2.4a	2.7a	5.4cd	5147a	5433a
Holyrood	3.7c	17a	29b	3a	0.3c	1.9ab	10.5bc	701h	1298d
Selangor	13.0bc	41a	131a	133a	1.2abc	2.7a	14.5b	1727e	3253b
Harimau	10.9bc	36a	36ab	8a	0.8abc	1.9ab	1.9ab	1399f	1212d
Rengam	12.0bc	11a	39ab	2a	0.5bc	0.7b	3.6d	1813de	1703c

[†] Each figure represents average values of tree- and inter-row.

[‡] Means within column segment followed by same letter are not significantly different at 0.05 level by DMNRT.

Table 45. Analysis of variance for chemical properties of nine Malaysian soils used for Hevea production.

Source of variation	Degree of freedom	pH (H ₂ O)		pH (KCl)		Δ pH		Organic matter	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	8	NS [‡]	6	NS	4	NS	5206	0.0001
Estate (Series), error (A)	5	1.2	--	1.1	--	1.2	--	26	--
Row	1	0.3	NS	0.03	NS	0.1	NS	2	0.01
Series x Row	8	0.5	NS	0.1	NS	0.4	NS	25	0.001
Row x Estate (Series), error (B)	5	0.3	--	0.04	--	0.1	--	0.5	--
Depth	1	0.1	0.02	0.02	NS	0.1	NS	18	0.0001
Series x Depth	8	0.5	0.01	0.2	0.0002	0.4	NS	96	0.0001
Row x Depth	1	0.03	NS	0.002	NS	0.1	NS	0.8	NS
Series x Row x Depth	8	0.2	NS	0.04	NS	0.1	NS	3	NS
Error (C)	146	3.9	--	1.0	--	4.4	--	57	--

Table 45. (Continued)

Source of variation	Degree of freedom	N KCl extractable					
		Acidity		ECEC		Al saturation	
		SS [†]	P > F	SS	P > F	SS	P > F
Series	8	425	0.0002 [†]	680	0.0001	2.10	NS
Estate (Series), error (A)	5	4	--	7	--	1.40	--
Row	1	1	0.0002	0.2	0.01	0.00	NS
Series x Row	8	4	0.0003	1.0	0.02	0.19	NS
Row x Estate (Series), error (B)	5	0.05	--	0.1	--	0.05	--
Depth	1	7	0.0001	4.1	0.0001	0.07	0.005
Series x Depth	8	24	0.0001	14.8	0.0001	0.02	NS
Row x Depth	1	0.01	NS	0.2	NS	0.004	NS
Series x Row x Depth	8	0.2	NS	1.4	0.03	0.07	NS
Error (C)	146	6.8	--	11.5	--	5.5	--

Table 45. (Continued)

Source of variable	Degree of freedom	N KCl extractable					
		Boron		Calcium		Magnesium	
		SS [†]	P > F	SS	P > F	SS	P > F
Series	8	0.9	NS [‡]	11.1	NS	430	0.0001
Estate (Series), error (A)	5	2.1	--	2.0	--	0.01	--
Row	1	0.03	NS	0.1	0.002	0.03	0.000
Series x Row	8	0.3	NS	3.4	0.0001	0.2	0.000
Row x Estate (Series), error (B)	5	0.2	--	0.02	--	0.002	--
Depth	1	0.4	0.0003	0.4	0.0003	0.001	NS
Series x Depth	8	0.5	0.04	2.3	0.0001	0.06	NS
Row x Depth	1	0.1	0.05	0.2	0.006	0.01	NS
Series x Row x Depth	8	0.3	NS	0.8	0.004	0.07	NS
Error (C)	146	4.2	--	82	--	0.7	--

[†]Sum of squares.[‡]Not significant (P > 0.05).

Table 46. Analysis of variance for mineral contents of nine Malaysian soils used for Hevea production, extracted by three reagents.

Source of variation	Degree of freedom	Phosphorus		Potassium		Calcium		Magnesium	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	16215	NS [‡]	164690	0.006	938192	0.0001	259759	0.0001
Estate (Series), error (A)	5	18770	--	7667	--	4332	--	343	--
Row	1	5583	0.045	370	NS	128	NS	1252	0.0001
Series x Row	8	4986	NS	7857	NS	303109	0.0001	12947	0.0001
Row x Estate (Series), error (B)	5	3973	--	6904	--	13003	--	22	--
Depth	1	8076	0.001	6915	0.0001	59829	0.004	3	NS
Series x Depth	8	2306	NS	3002	NS	198705	0.003	3090	NS
Row x Depth	1	1903	NS	357	NS	149	NS	233	NS
Depth x Estate (Series x Row), error (C)	18	9520	--	4733	--	95231	--	3001	--
Extractant	2	46308	0.0001	65099	0.0001	832	NS	13656	0.0001
Series x Extractant	16	23851	0.0001	34119	0.0001	15060	0.001	23293	0.0001
Row x Extractant	2	4089	0.0001	618	NS	390	NS	277	NS
Depth x Extractant	2	7542	0.0001	1337	0.01	1280	NS	212	NS
Error (D)	498	111742	--	70846	--	181523	--	31025	--

Table 46. (Continued)

Source of variation	Degree of freedom	Copper		Zinc		Manganese		Iron		Aluminum	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	110	NS [‡]	78	NS	23383	NS	112654656	0.01	159232187	NS
Estate (Series), error (A)	5	19	--	28	--	7149	--	7108597	--	40942830	--
Row	1	0.0004	NS	9	0.02	196	0.001	104596	0.01	135286	NS
Series x Row	8	16	NS	19	NS	500	0.003	694260	0.01	1516750	NS
Row x Estate (Series), error (B)	5	7	--	4	--	19	--	37405	--	277007	--
Depth	1	8	0.02	4	0.05	658	0.001	63782	0.04	496	NS
Series x Depth	8	12	NS	21	0.03	1505	0.002	3470412	0.0001	2534283	0.004
Row x Depth	1	0.7	NS	0.3	NS	31		624	NS	15704	NS
Depth x Estate (Series x Row), error (C)	18	25	--	16	--	678	--	236505	--	1267288	--
Extractant	2	48	0.0001	81	0.0001	2817	0.0001	368749040	0.0001	200227662	0.0001
Series x Extractant	16	40	0.0001	20	NS	2053	0.0001	195474566	0.0001	118793314	0.0001
Row x Extractant	2	0.03	NS	0.2	NS	41	NS	82200	NS	148629	NS
Depth x Extractant	2	1	NS	0.3	NS	55	NS	80122	NS	64566	NS
Error (D)	498	313	--	380	--	8250	--	29390348	--	65326516	--

[†]Sum of squares.[‡]Not significant (P > 0.05).

Table 47. Analysis of variance for mineral contents in Hevea leaves for four clones.

Source of variation	Degree of freedom	Phosphorus		Potassium		Calcium		Magnesium		Copper	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	0.02	0.0001 [‡]	2.7	0.0001	0.70	0.0001	0.03	0.0001	237	0.0001
Estate (Series)	1	0.0006	0.02	0.0001	NS	0.01	NS	0	NS	20	0.02
Clone	3	0.004	0.0001	0.3	0.001	1.17	0.0001	0.04	0.0001	2	NS
Series x Clone	3	0.004	0.0001	0.2	0.01	0.53	0.0001	0.03	0.0001	7	NS
Error	32	0.003	--	0.4	--	0.31	--	0.007	--	100	--

Table 47. (Continued)

Source of variation	Degree of freedom	Zinc		Manganese		Iron		Aluminum		Boron	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	2453	0.0001 [‡]	75853	0.0001	2756	0.0001	19038	0.0001	1199	0.0001
Estate (Series)	1	368	0.001	2993	0.0004	122	NS	17	NS	0	NS
Clone	3	67	NS	45686	0.0001	4518	0.0001	3818	0.0001	90	0.003
Series x Clone	3	200	NS	54758	0.0001	3126	0.0001	3533	0.0001	51	0.03
Error	32	839	--	6109	--	1810	--	3051	--	163	--

[†]Sum of squares.[‡]Not significant ($P > 0.05$).

Table 48. Analysis of variance for mineral contents in Hevea bark for four clones.

Source of variation	Degree of freedom	Phosphorus		Potassium		Calcium		Magnesium	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	984557	0.0001 [†]	1.3	0.0001	14.9	0.0001	0.05	0.0001
Estate (Series)	1	6211	NS	0.004	NS	0.2	0.0002	0.03	0.0001
Clone	3	162410	0.0001	0.6	0.0001	15.8	0.0001	0.05	0.0001
Series x Clone	3	384923	0.0001	0.7	0.0001	8.0	0.0001	0.10	0.0001
Year	1	61661	0.0001	0.5	0.0001	0.2	0.002	0.01	0.0001
Series x Year	8	202161	0.0001	2.2	0.0001	2.8	0.0001	0.04	0.0001
Clone x Year	3	241935	0.0001	0.6	0.0001	0.01	NS	0.004	0.01
Series x Year x Clone	3	345253	0.0001	0.3	0.002	0.09	NS	0.02	0.0001
Error	65	124349	--	1.3	--	1.0	--	0.02	--

Table 48. (Continued)

Source of variation	Degree of freedom	Copper		Zinc		Manganese		Iron	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	16204	0.0001 [‡]	5582	0.0001	277240	0.0001	38615	0.0001
Estate (Series)	1	456	0.002	444	0.0001	8748	0.0001	1564	0.0001
Clone	3	1706	0.0001	3094	0.0001	174284	0.0001	1920	0.001
Series x Clone	3	13880	0.0001	358	0.0001	115250	0.0001	1961	0.001
Year	1	1829	0.0001	667	0.0001	52781	0.0001	7298	0.0001
Series x Year	8	3506	0.0001	842	0.0001	41607	0.0001	5134	0.0001
Clone x Year	3	1135	0.0001	25	NS	11383	0.0001	127	NS
Series x Clone x Year	3	338	NS	27	NS	1206	0.01	1379	0.004
Error	65	2823	--	591	--	6135	--	6159	--

Table 48. (Continued)

Source of variation	Degree of freedom	Aluminum		Boron	
		SS [†]	P > F	SS	P > F
Series	8	2425662	0.0001 [‡]	112	0.0001
Estate (Series)	1	20917	NS	8	0.01
Clone	3	110339	0.001	9	NS
Series x Clone	3	153055	0.0001	16	0.01
Year	1	34732	0.02	63	0.0001
Series x Year	8	2059553	0.0001	41	0.0002
Clone x Year	3	44422	0.05	4	NS
Series x Clone x Year	3	40456	NS	13	0.01
Error	65	362068	--	72	--

[†]Sum of squares.

[‡]Not significant (P > 0.05).

Table 49. Analysis of variance for mineral contents in Hevea bark-scrap rubber for four clones.

Source of variation	Degree of freedom	Phosphorus		Potassium		Calcium		Magnesium	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	401377	0.0001 [†]	1.7	0.0001	28	0.0001	0.08	0.0001
Estate (Series)	1	363	NS	0.2	0.0001	0.2	NS	0.004	0.03
Clone	3	1402130	0.0001	0.5	0.0001	17	0.0001	0.10	0.0001
Series x Clone	3	552621	0.0001	0.5	0.0001	1.6	0.01	0.11	0.0001
Year	1	35420	0.01	0.1	0.0003	1.7	0.002	0	NS
Series x Year	8	627693	0.0001	0.3	0.001	4	0.01	0.01	NS
Clone x Year	3	21919	NS	0.3	0.0001	0.9	NS	0.01	0.002
Series x Clone x Year	3	101092	0.001	0.2	0.0002	0.7	NS	0.005	NS
Error	65	363314	--	0.6	--	63.8	--	0.05	--

Table 49. (Continued)

Source of variation	Degree of freedom	Copper		Zinc		Manganese		Iron	
		SS [†]	P > F	SS	P > F	SS	P > F	SS	P > F
Series	8	6602	0.0001 [‡]	8070	0.0001	183400	0.0001	685	0.02
Estate (Series)	1	75	NS	456	0.004	13467	0.01	133	0.06
Clone	3	1808	0.0001	347	NS	172721	0.0001	587	0.002
Series x Clone	3	3122	0.0001	2642	0.0001	63931	0.0001	2627	0.0001
Year	1	57575	0.0001	630	0.001	56	NS	45	NS
Series x Year	8	5465	0.0001	1817	0.0002	8262	NS	798	0.01
Clone x Year	3	1258	0.0001	69	NS	1675	NS	426	0.01
Series x Clone x Year	3	2020	0.0001	343	NS	3350	NS	1663	0.0001
Error	65	2784	--	3310	--	139976	--	2286	--

Table 49. (Continued)

Source of variation	Degree of freedom	Aluminum		Boron	
		SS [†]	P > F	SS	P > F
Series	8	461804	0.0001 [‡]	602	0.0001
Estate (Series)	1	3367	NS	0.8	NS
Clone	3	12480	0.03	92	0.0001
Series x Clone	3	42368	0.0001	139	0.0001
Year	1	20184	0.0003	34	0.002
Series x Year	8	244485	0.0001	495	0.0001
Clone x Year	3	1114	NS	189	0.0001
Series x Clone x Year	3	6790	NS	62	0.001
Error	65	88297	--	215	--

[†]Sum of squares.

[‡]Not significant ($P > 0.05$).

Table 50. Comparisons of Ca and K values in three extracting solutions by atomic absorption and flame emission spectrophotometry, respectively.[†]

Standard in 0.1 <u>N</u> HCl [‡]	Ca recovered			K recovered		
	DA	<u>N</u> HCl	5 <u>N</u> HCl	DA	<u>N</u> HCl	5 <u>N</u> HCl
-----ppm-----						
0	0	0	0	0	0	0
10	10	9	6	10	9	7
50	50	47	31	50	44	36
100	100	96	63	100	90	70

[†]Each standard includes 12,500 ppm La.

[‡]Standard curve for all determinations set in 0.1 N HCl.

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BIOGRAPHICAL SKETCH

Zin Zawawi Hj Zakaria was born on December 12, 1949, in Johore, Malaysia. He received his primary and secondary education at Kluang, Johore, and completed his Senior Cambridge Certificate in 1966 from Secondary English School Kluang.

He graduated with a Diploma in Agriculture from the College of Agriculture at Serdang, in 1970. He was appointed as a Rubber Instructor by the Rubber Research Institute of Malaysia (RRIM) upon his graduation and served for two years in the Smallholders Advisory Service (SHAS), at Machang, Kelantan.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Nathan Garmon, Jr., Chairman
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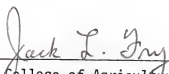
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